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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
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THE CONTINUATION OF A DAMAGE CONTROL STABILITY MODULE FOR THE FFG-7

by

CHARLES ARTHUR BUSH
LIEUTENANT, UNITED STATES NAVY

O.E.
S.M. (NA&ME)

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CHARLES ARTHUR BUSH

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ABSTRACT

The Damage Control Stability Module for the FFG-7 class Guided Missile Frigate is an interactive computer program which performs the load accounting, calculates the hydrostatic and stability parameters, and provides the operator with the recommendations necessary to counter the flooding threat to the stability of the ship. The continuation of the development of this program was undertaken to provide a more accurate prediction of the ship's final flooded state throughout the range of trim expected as a result of damage.

An investigation of the effect of trim on the hydrostatic and stability parameters which define the state of the ship was carried out to determine the effect of trim dependent variances of these parameters on the accuracy of the Stability Module. In addition, a sensitivity analysis was performed to ascertain the Module's sensitivity to inaccurate input data. The input data considered was limited to the intact liquid load accounting of the ship. An extension of the program's data base was also undertaken.

The effects of trim on the pertinent hydrostatic and stability parameters were found to vary with trim, resulting in variances of these quantities over the conventional methods of calculation. Therefore, these quantities were installed in the Module for various trims to improve the accuracy of the output. The results of the sensitivity analysis led to the conclusion that the Module is relatively insensitive to reasonable inaccuracies in the input liquid load accounting. The data base was extended to include all watertight subdivisions below the second deck. A section of recommended future study is provided.

Thesis Supervisor: Professor David V. Burke, Jr.
Title: Professor of Ocean Engineering

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1.0 INTRODUCTION

The hazard of flooding may be described as the failure of the ship's system of watertight integrity. This failure results in a loss of reserve buoyancy with a subsequent loss of static and/or dynamic stability. This loss of stability feeds back to the system, resulting in a further loss of reserve buoyancy until the ship reaches an equilibrium position or total defeat of the watertight integrity system occurs and the ship is lost. In addition to the obvious severity of this threat, flooding is historically the most frequently encountered form of damage sustained by naval ships during combat operations. Therefore, both passive and active methods of flooding protection must be available to the crew to counteract this threat to the survivability of the ship.

Passive measures of flooding protection are normally design features incorporated into the ship such as watertight subdivision, a minimum number of penetrations through watertight boundaries, armor plating, and protection of sea water systems from fragmentation damage. These features are beyond the control of the damage control organization, except for maintenance, and are taken as constants in the stability analysis of the ship.

Active measures, such as proper liquid load management and proper setting of watertight closures, are performed prior to the inception of damage and play a critical role in the ability of the ship to survive damage. These conditions vary and must be considered as an input; determining the initial state of the ship prior to damage. After damage, the first active measure to be performed is the detection of occurrence. Although the detection of rapid uncontrollable flooding is

generally of little value, further active efforts such as plugging, dewatering, and counterflooding are very effective in counteracting the effects of slow to moderate flooding rates. However, the key factor is the timely detection of the flooding while effective damage control efforts can still be brought to bear on the stability threat.

Once detection has been accomplished and the present state of the ship determined, the efforts of the damage control organization must be directed towards the most severe, yet controllable, flooding. As hydrostatic and stability calculations can be quite long and tedious, particularly while the ship is in a damaged condition, a computer program capable of performing these calculations and providing the ship's stability characteristics for the present condition, final flooded condition, and condition after some prospective corrective action has many obvious advantages. With this information the Damage Control Officer can direct the damage control effort, ensuring that the final flooded state is survivable from the stability standpoint. This is of particular importance during major damage as the resources of the ship, pumping capacity for example, may be limited such that only a portion of the total damage may be counteracted at a time. The ability to have the effects of all considered corrective actions on hand, prior to initiation, enables the Damage Control Officer to have full confidence in the effective utilization of his resources in countering the flooding threat.

In this manner, computer-aided Damage Control can enhance the survivability of a ship. There are certainly damaged conditions for any ship that would not require use of such a system. However, between the extreme conditions of minor flooding and immediate loss of the ship there are many scenarios that could be far better managed with a

Stability Module. A study of War Damage Reports from the Second World War indicates that the number of these scenarios grows for larger and more complex ship types, as the options open to the Damage Control Officer to counter a specific flooding hazard increase.

1.1 BACKGROUND

The development of a Stability Module for the FFG-7 class Guided Missile Frigate has been tasked by the Naval Sea Systems Command to the David Taylor Naval Ship Research and Development Center (DTNSRDC) Annapolis, Maryland (Code 2731). The initial program architecture was developed by LT Jeffrey R. Sander USN in his Ocean Engineer's thesis at the Massachusetts Institute of Technology in the Spring of 1983 [8]. The Stability Module is to be incorporated into the Damage Control Console of the FFG-7, which is described below. In addition, the program architecture is to be such that a minimum effort is required to adapt the module to a different ship type. The purpose of this thesis is the further development of the Stability Module for the FFG-7 including improved calculation techniques and the investigation of its utilization. The specific issues covered are effects of trim on hydrostatic and stability calculations and the sensitivity of the module to errors in input data. In addition, a detailed study of the World War Two War Damage Reports and interviews with Naval Officers have also led to the preliminary development of a Damage Control Logic and the identification of the information required from the module to implement this logic.

The Damage Control Console (DDC) installed on the FFG-7 class Guided Missile Frigate is a single-unit console located in the ship's Central Control Station. The system monitors and provides the operator with status of and alarm conditions for selected shipboard systems that would require evaluation during an emergency condition. The DCC also allows the operator to remotely control key elements of the ship's fire-fighting and flooding control systems. The systems monitored and/or controlled by the DCC are the Aqueous Film Forming Foam (AFFF) Sprinkling system, HALON Flooding system, Vital Compartment High-Water sensors, Firefighting Water Sprinkling systems, Compartment Smoke and High Temperature sensors, Ventilation and Ducting systems, Firemain system, and DCC Status and Test systems. The Stability Module will possess the same management capability for the control of flooding. As will be described, the Stability Module will assess the stability of the ship through either automatic or manual input of the existing loading and flooding conditions, and provide the operator with recommendations for possible corrective actions to counter any adverse stability conditions.

1.2 KEY FACTORS AND REQUIREMENTS OF COMPUTER-AIDED DAMAGE CONTROL

The prediction of the final flooded state of a damaged ship is dependent on a complex set of parameters ranging from the material condition of the ship to the environmental conditions in which the ship must survive and operate. In addition, although the stability of the ship is the critical issue of any damage control effort, the mobility and mission capability of the ship as a weapons platform will also be of

prime concern under the battle conditions which led to the damage. Therefore, a computer-aided damage control system must be capable of not only determining the stability of the ship but also identifying potential losses of major system components, from both a mobility and weapons/sensors standpoint, as a result of the damage. The term "computer-aided" must also be stressed as the hardware and software associated with the system can only assess the state of stability for a damaged condition. War Damage Reports detail many examples of ships surviving, or not surviving damage as a result of the performance and actions of the damage control teams.

The accuracy of the current, intermediate, and final states of the ship is also a key factor. Obviously, a computer-aided system must provide results at least to the order of accuracy expected from hand calculations and observations. A program which does not provide the proper draft readings for daily reports can not be expected to be used by the ship's company during battle to predict the ship's ability to survive a given damaged condition. Conversely, as many stability calculations involve approximations, a requirement to predict the exact state of the ship can not be met, even if the loading of the ship was exactly known. However, standard calculations and approximations have been shown to provide sufficiently accurate results to predict when the stability of a damaged ship will become critical. At this point, the intuitive judgement and responsibility of the Captain and the Damage Control Officer must prevail in determining whether the ship is to be abandoned or not. A further issue relating to the accuracy of a Stability Module is the required accuracy of the inputs to obtain such results. Additional computational time is clearly not warranted when tank soundings are

accurate only to that which can be expected from the current practice of sounding tape readings from a single point in each tank. The Sensitivity Analysis section, presented later, will discuss this area in greater detail.

As mentioned previously, rapid flooding is often uncontrollable with respect to the crew's ability to contain the subsequent stability threat. For this type of major damage, the passive Damage Control measures designed into the hull must be capable of confining the flooding to an acceptable extent. War Damage Reports for destroyer-type ships lead to the conclusion that initial rapid flooding, caused by an opening in the hull, will reach a quasi-equilibrium stage in ten to fifteen minutes. Further progressive flooding is normally characterized as slow and controllable. Additionally, ship's power is often lost either due to flooding of machinery spaces or shock from the detonation of the weapon.

As a result of this common mode of progressive flooding, two further requirements are imposed on a computer-aided Damage Control system. First, the computer, and its associated systems, must be capable of functioning without ship's power. This requirement is to be satisfied by the planned installation of the Module in a mini-computer with a back-up battery power supply. Secondly, the system must be able to rapidly predict various states of flooding in a form that does not saturate the ability of the Damage Control Officer to comprehend the true meaning of the data. This requirement translates into clear, concise output formatting, detailing only those parameters required to make the immediate action decisions required to save, or conversely abandon, the ship. During the restoration phase of the damage control

effort, an extended information format should be utilized to ensure a safe return to the best possible stability condition. A plan for a graphics output, which would meet this requirement, is detailed in the Recommendations section.

1.3 DAMAGE CONTROL LOGIC

Once flooding has occurred and has been contained to an extent which allows the damage control effort to dewater the ship, a logic should be implemented which will bring the ship to its most stable state in the shortest period of time. Unfortunately, differences in various ship designs prevent the generation of general rules beyond the standard practices available today. However, certain criteria should be met in all cases of restoration, which can be quickly identified and presented by a Stability Module.

A review of current U.S. Naval damage control practice reveals that no or little guidance is offered for the actual sequence of restoration. The prime reason for this is that the Damage Control Officer is expected to have no or very little hard knowledge of the actual condition of the ship. Instead, for each ship type, a Flooding Effect Diagram has been generated depicting all watertight subdivisions in color-coded deck layouts. Each watertight subdivision is color-coded to reflect its general effect on the stability of the ship, as follows.

> Pink - Flooding causes a decrease in stability due to its height above the center of gravity or free surface or both. In the flooded condition, these spaces should be either dry or complete full.

Green - Flooding of these spaces will improve stability if trim is maintained, even though free surface may exist.

Yellow - Flooding will improve stability only if no free surface exists, if not completely full stability will be impaired.

White - These spaces have no appreciable effect on stability. Although these diagrams provide the crew with a method of dealing with any flooded condition, much more efficient damage control could be accomplished given a computer based system of stability management.

Active damage control measures should be directed towards achieving the maximum rate of restoration of lost buoyancy and stability reserves. For multiple compartment flooding, this requires a numerical analysis, in most cases, to determine the effect of each proposed corrective action. The guidance required for this type of decision making are as follows:

a) Reserve buoyancy and stability necessary for survival;

b) Size, number, and location of watertight boundary disruptions;

c) Volumes and locations of affected and adjacent spaces;

d) Vital functions of affected and adjacent spaces;

e) Flow rates of available dewatering equipment;

f) Relative time requirements for effecting proposed corrective actions.

The guidance item concerning space vital functions is critical as it is important to recognize that the mission capability of the ship is directly related to the damage control effort. A ship damaged in battle will most likely stay in the battle until its propulsion plant, steering

gear, and control systems are brought back into operation. Therefore, mission capability, or mobility for evasion, may take an equal or even greater priority than the actual stability of the ship. This situation is compounded in light of the movement towards more complex combat systems and higher degrees of integration between ship subsystems.

Therefore, damage control logic is directly dependent on both the stability effects of each watertight subdivision and the "situational" priorities at the time of damage. Assuming the Stability Module can identify vital system conponents in danger, based on a priority list of systems, the problem of restoration becomes one of single compartment effects. Based on the stability problem most critical at the time (i.e., GM, list, trim, area under the righting arm curve, etc.) each flooded compartment can be rated as to its potential benefit to the stability item in question. This information would allow the Damage Control Officer to make logical decisions to efficiently improve the stability characteristics. It is also important to check transient conditions which will occur during corrective dewatering or flooding evolutions for any degradation of stability due to free surface effects. Due to the great number of calculations required and the size of the data base, the above logic can only be efficiently processed by a computer based system.

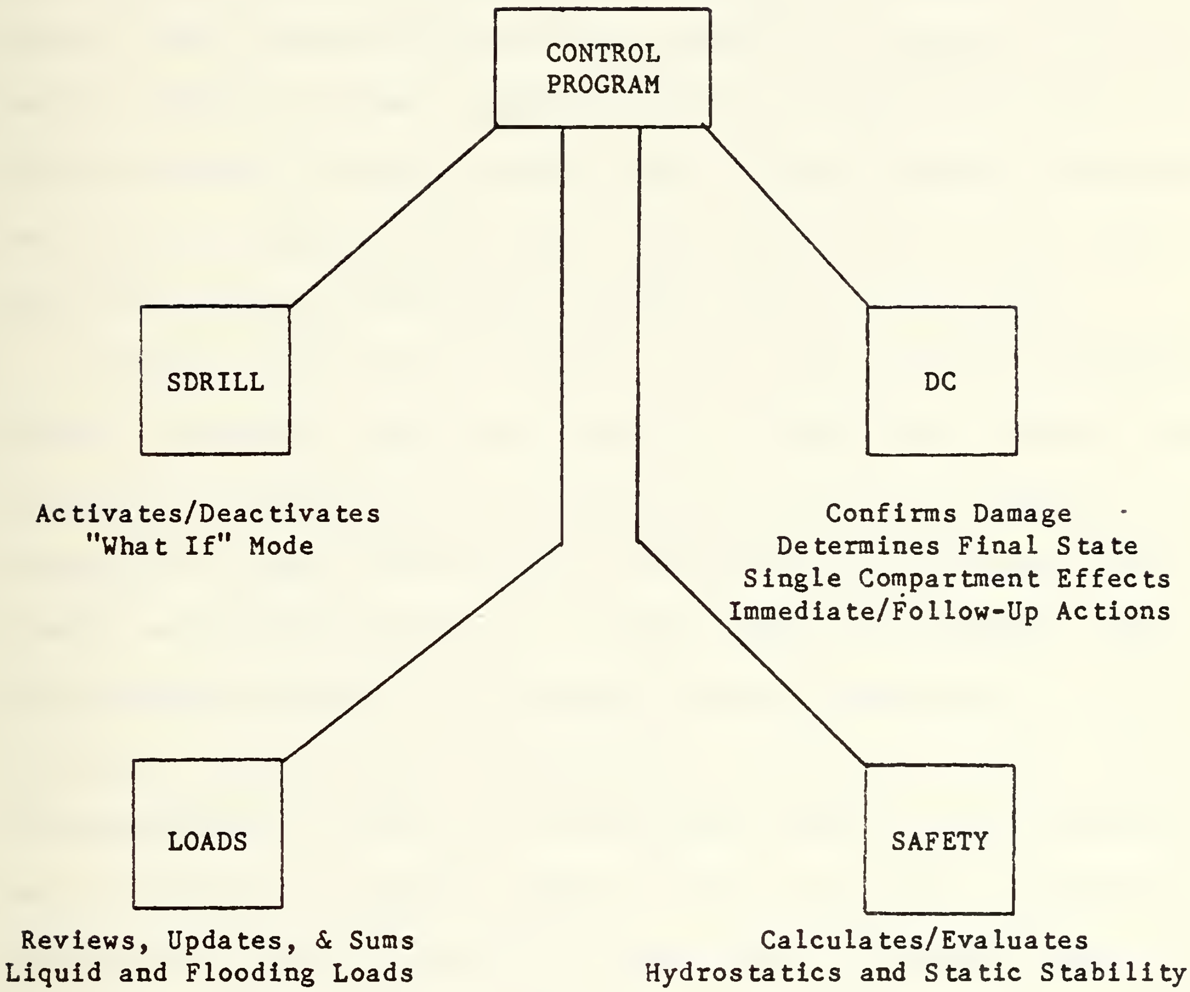
1.4 PROGRAM DESCRIPTION

A brief description of the Stability Module follows in order to acquaint the reader with its capabilities. For detailed information on the program structure, the reader is referred to LT Sander's thesis [8].

Algorithms developed during this thesis will be detailed in subsequent chapters; but, these changes have not altered the program architecture. In general, the module performs the load accounting required to calculate the basic hydrostatic and stability parameters required to determine the final flooded state of the ship. In addition, the module also presents the user with recommended damage control actions to counter the flooding threat to stability. The user may opt to investigate the effects of any recommendation, having the module re-evaluate the final stability conditions. To accomplish this, three working sets of data are maintained for the actual, final flooded, and drill conditions. A flow chart of the main program functions is depicted in figure 1.1.

In the load accounting section of the module, the user inputs soundings for a set of selected tanks and compartments. The program then calculates the weights, centers of gravity, and transverse moments of inertia for each selected space. Tank and compartment sounding tables reside in random-access data files containing the required parameters for six sounding levels. The parameters for the given sounding are calculated by linear interpolation. The interpolation error is minimized by choosing the six soundings that correspond to the major changes in curvature of the various capacity curves. For most tanks and compartments, these correspond to sounding levels of approximately 0%, 10%, 25%, 50%, 75%, and 100%. The volume permeability for each watertight subdivision group is included as a multiplicative factor to the capacity curve. These factors were chosen as a function of space usage as described by Sarchin and Goldberg [9]. All weights, centers, and inertias are summed under various liquid load accounts, reflecting the tank usage, and a flooding account. The capability for remote sensing

Figure 1.1 Flow Chart of Stability Module



units to input the sounding levels directly to the program is provided. Static loads and non-liquid variable loads such as crew, ammunition, stores, and aviation weights, are presently input to the program from a summary data file and can not be interactively changed by the module.

The stability evaluation section of the program calculates the hydrostatic parameters for the displacement and longitudinal center of gravity (LCG) calculated from the load summation. The ship's curve of static stability is then calculated with the standard corrections for vertical center of gravity position (KG), off-center weights, and wind conditions. These parameters are then displayed to the user with a brief explanation of the current stability condition of the ship.

The next section of the program is the Damage Control Evaluation Module. Initially, the user is asked to confirm, and identify the source of, all previously input flooded compartments. If flooding is in progress, the final flooded state is calculated and the loading, hydrostatic, and stability parameters for this state are displayed. Then, the hydrostatic effect of each damaged watertight subdivision is calculated and displayed with recommendations for further action. These recommendations are based on the hydrostatic effect of the compartment and its effect on stability similar to the color-coding described in Section 1.3. They are also made in two stages: immediate action and follow-up action. At each stage of the recommendations section, the user can investigate the effects of a proposed corrective action. Therefore, the module, in its present form, has the ability to supply the operator with all the necessary information to carry out an effective damage control effort.

1.5 FEATURES ADDED TO THE STABILITY MODULE

The major thrust of this thesis is the investigation of the effect of trim on the hydrostatic and stability parameters which define the state of the ship. These trim effects were developed in order to ascertain the variances of each parameter as a function of trim. Once these variances were determined, their effect on the calculations used by the Module to predict the ship's state was compared to the standard method of hydrostatic and stability calculations. The inclusion of these parameters, as a function of trim, into the Module was based on the improvement in the ability of the program to accurately determine the stability of the ship. The changes made to the program code are detailed in Chapters 2, 3, and 4 with program listings in Appendix E.

A sensitivity analysis of the program was also performed to determine the effect of inaccurate input data on the output of the program. Clearly, any effort to improve the accuracy of the program would be nullified if the input was intolerant to a reasonable amount of error. In order to perform this analysis, qualitative assumptions were made with regard to the level of accuracy of the current methods of tank level determination.

In addition, the sounding tables for the FFG-7 were completed for all tanks and watertight subdivisions from the second deck down. These sounding tables were prepared as discussed in Section 1.4 and are presented in Appendices A and B for tanks and compartments, respectively.

2.0 HYDROSTATICS AS A FUNCTION OF TRIM

The hydrostatic parameters used for standard damaged stability calculations are normally not expressed as functions of trim. The common practice is to use the appropriate zero trim case parameter for all loading cases, regardless of the trim. This approximation yields satisfactory results for cases not involving extreme loading conditions or large trims. This method has the added advantage of the minimum number of calculations to perform, making it a popular method. However, for the Stability Module to be as accurate as possible, under all cases of loading and flooding, the hydrostatic parameters must include the effects of the trim of the ship. Also, the number of additional calculations the module must perform, as a result of the inclusion of the trim effects, should not result in a significant increase in time required for calculation purposes. Consequently, improved accuracy throughout the range of loading conditions and reliable results at high trim conditions are available with no noticeable degradation in the speed of execution.

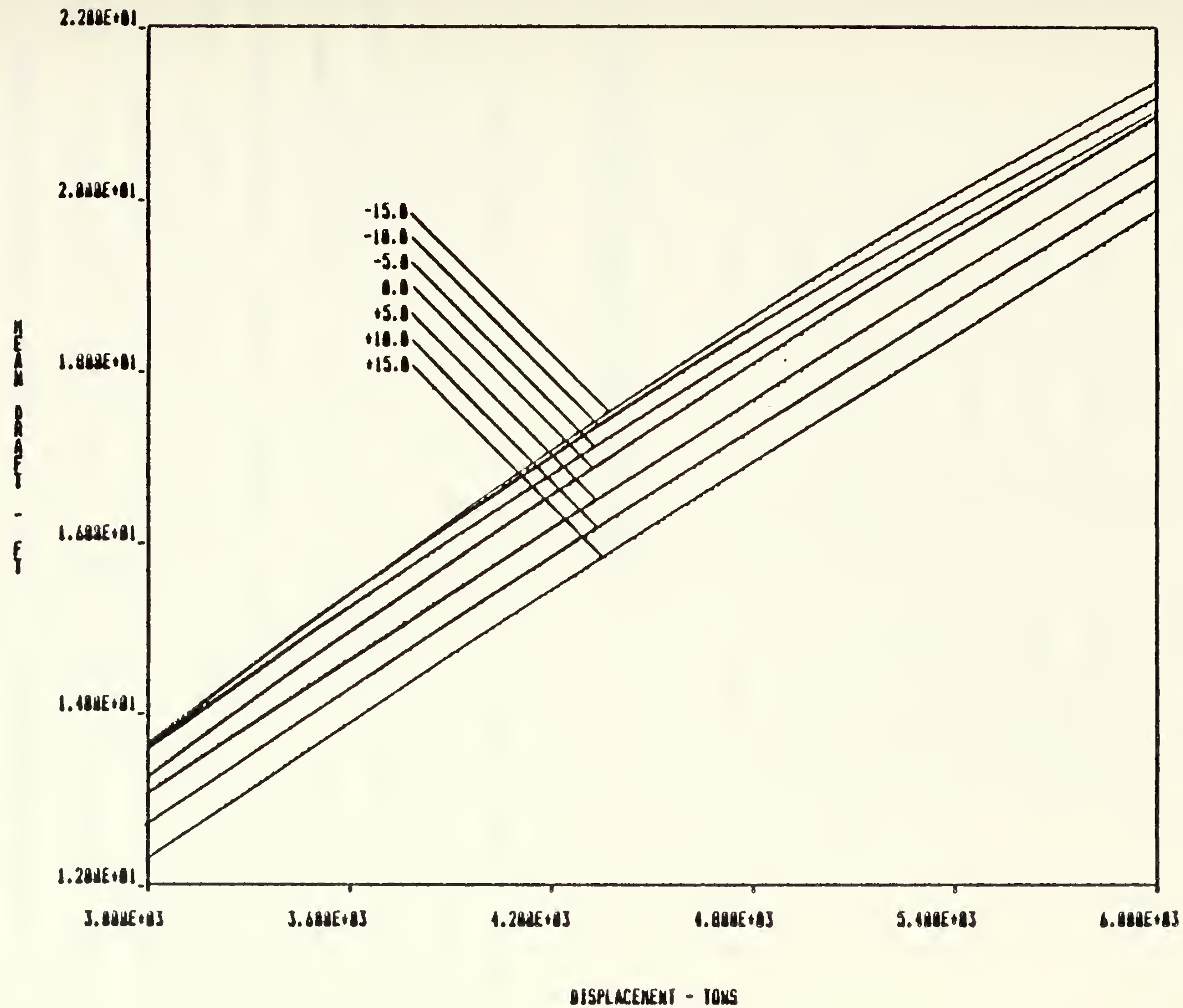
The program used to generate the basic hydrostatic parameters as a function of trim was the NAVSEA program 'SHCP', the Ship's Hull Characteristic Program. The curves of form were computed for the zero trim case and compared to the FFG-7 Curves of Form (NAVSHIPS Drawing No. 802-4386542). The input set of offsets was adjusted until good correlation was observed between the computed values and the actual values. This adjustment of the input was necessary due to the integration and curve fitting routines used in 'SCHP', as some combinations of offsets did not yield the proper section shapes in the program. After the input

offset table was determined to be satisfactory, trim cases of 15.0, 10.0, 5.0, -5.0, -10.0, and -15.0 feet were run, with positive trim indicating down by the stern. For each trim case, the hydrostatic parameters were fitted, by the least-squares method, to second, third, or fourth order polynomials. The mean draft was chosen to be a function of displacement, and all other parameters were chosen as functions of the mean draft. The order of the curve fit was determined by the smallest order yielding a correlation factor of 0.98 or better. The correlation factor is a measure of the error between the polynomial evaluation and the actual data. A value of 1.00 indicates a perfect curve fit. In all but a few cases the correlation factors were greater than 0.99, indicating excellent correlation. The range of draft utilized for the curve fits was 12 to 20 feet, which was assumed to represent the limits of mean draft over all loading cases. The selection of +/-15 feet of trim as a upper and lower trim bound was based on hand calculations for severe flooding at the extremities of the ship. The following sections describe each hydrostatic parameter's dependence on trim and the consequences of these dependencies. In addition, a graphical representation of each parameter as a function of trim is included.

2.1 MEAN DRAFT AS A FUNCTION OF DISPLACEMENT

As can be seen in figure 2.1, the mean draft for a given displacement increases as the ship goes from a stern down to bow down attitude. This is due to the fineness of the bow causing a loss of buoyancy as the ship trims down by the bow about the longitudinal center of flotation. This lost buoyancy must be regained by a settling of the ship, resulting

Figure 2.1 - Mean Draft vs Displacement
for Trims of +/-15.0, +/-10.0, +/-5.0, and 0.0 Feet



in an increase in draft. This is the same phenomenon which is normally accounted for by the Change in Displacement Per Foot Trim Aft (CDPFTA) hydrostatic function; therefore, CDPFTA need not be calculated in the module. The following are the least square fits for the mean drafts, T, as a function of displacement, Δ, for the trim cases.

$$T_{15} = 3.9223 + 2.934 \times 10^{-3}\,\Delta - 4.61 \times 10^{-8}\,\Delta^2$$

$$T_{10} = 4.309 + 2.9425 \times 10^{-3}\,\Delta - 4.809 \times 10^{-8}\,\Delta^2$$

$$T_{5} = 4.8237 + 2.8762 \times 10^{-3}\,\Delta - 4.2 \times 10^{-8}\,\Delta^2$$

$$T_{0} = 4.0148 + 3.3559 \times 10^{-3}\,\Delta - 8.8484 \times 10^{-8}\,\Delta^2$$

$$T_{-5} = 4.2923 + 3.4086 \times 10^{-3}\,\Delta - 1.0301 \times 10^{-7}\,\Delta^2$$

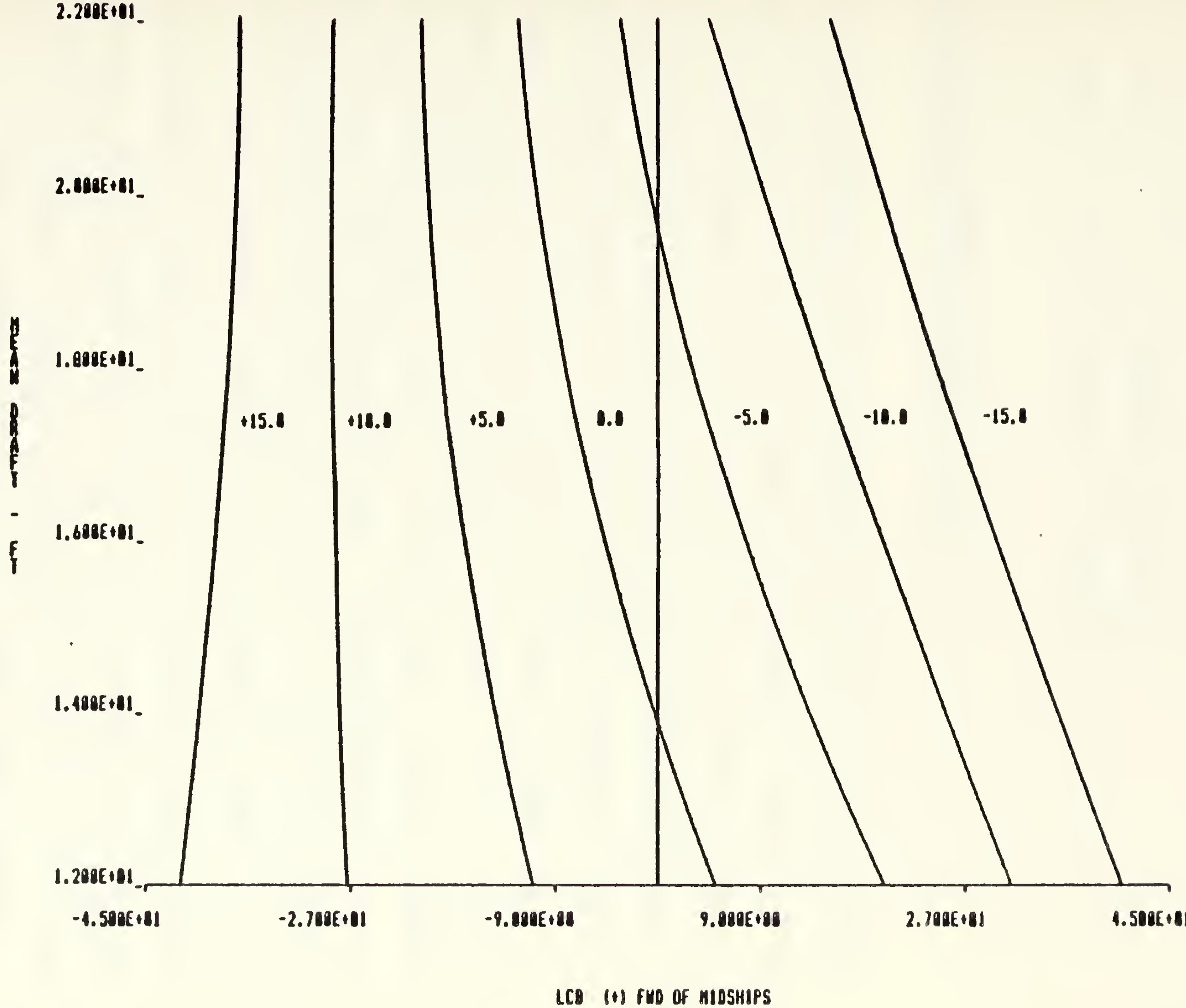
$$T_{-10} = 3.3384 + 3.9062 \times 10^{-3}\,\Delta - 1.556 \times 10^{-7}\,\Delta^2$$

$$T_{-15} = 2.8254 + 4.0911 \times 10^{-3}\,\Delta - 1.666 \times 10^{-7}\,\Delta^2$$

2.2 LONGITUDINAL CENTER OF BUOYANCY (LCB)

As can be seen in figure 2.2, the LCB is a well-behaved function with respect to trim. As the ship trims down by the bow more volume is immersed forward and less aft. As it is the longitudinal centroid of the underwater volume, the LCB moves forward; and, conversely, aft for the stern down case. These curves also demonstrate the positive longitudinal stability characteristics inherent to hull forms. For example, if the longitudinal center of gravity moves aft a positive trim occurs. Figure 2.2 shows that the LCB will also move aft to coincide with the LCG, defining the trim. This is the basis for the hydrostatic calculations to be detailed in Chapter Four. The following are the curve fits for the various LCB's as a function of mean draft, T.

Figure 2.2 - Mean Draft vs LCB
for Trims of +/-15.0, +/-10.0, +/-5.0, and 0.0 Feet



$$LCB_{15} = -58.245 + 1.811\ T - .03769\ T^2$$

$$LCB_{10} = -18.255 - 1.0887\ T + .0284\ T^2$$

$$LCB_{5} - 24.584 - 4.0275\ T + .0892\ T^2$$

$$LCB_{0} = 56.83 - 5.7145\ T + .11688\ T^2$$

$$LCB_{-5} = 80.93 - 6.578\ T + .12498\ T^2$$

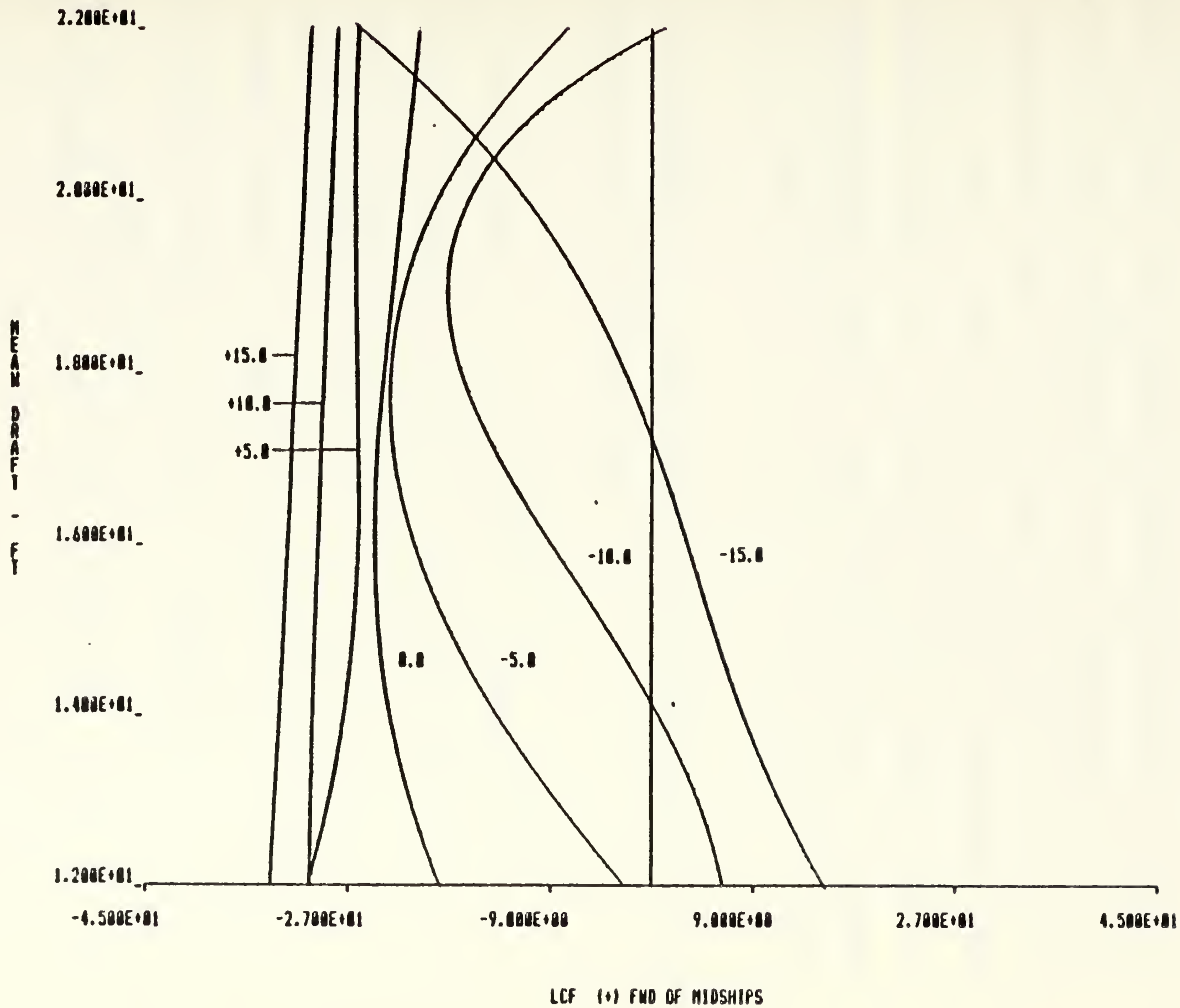
$$LCB_{-10} = 71.27 - 3.7243\ T + .03144\ T^2$$

$$LCB_{-15} = 81.114 - 3.7911\ T + .03619\ T^2$$

2.3 LONGITUDINAL CENTER OF FLOTATION (LCF)

The LCF is defined as the longitudinal centroid of the waterplane. For positive trims, the LCF is relatively independent of the mean draft, in the range of interest, as the bow sections do not immerse sufficiently for the flare to significantly alter the shape of the waterplane. As the positive trim decreases to a zero trim case, the effect of the bow flare causes the LCF to move forward. This effect continues, and becomes more pronounced, as the trim becomes negative. As can be seen in figure 2.3, bow down trims exhibit a somewhat more radical behavior, although the basic trend remains the same. This nonlinearity is due to the combined effects of the flare of the forward sections and the deadrise of the after sections common to a destroyer-type hull. As low drafts and negative trims leave only a small portion of the stern sections wetted, the waterplane area aft is small and the LCF is forward. As the draft increases, the gain of waterplane area aft predominates over the gain forward and the LCF shifts aft. This trend continues as the draft increases until the wall-sidedness of the stern sections result in no further increase in the waterplane area aft. At this

Figure 2.3 - Mean Draft vs LCF
for Trims of +/-15.0, +/-10.0, +/-5.0, and 0.0 Feet



point, the flare of the bow causes an increase in the area of the waterplane forward, resulting in the LCF moving forward.

As a result of this effect of trim on the LCF, the drafts at the forward and after perpendiculars will be different from those calculated by the conventional method. Although the differences between the two methods are not great, less than ten percent, the effects are most pronounced in the cases of weights added at the extremities of the ship. For a weight added at the bow, the conventional method underestimates the bow draft; and for a stern weight addition the conventional method overestimates the draft aft. In each case, if this weight is water in free communication with the sea, the iteration performed to determine the final state would possess the respective error, yielding inaccurate results.

The following are the equations derived for the LCF as a function of mean draft, T, for the various trims.

$$LCF_{15} = -39.03 + .509554\ T - 8.5672 \times 10^{-3}\ T^2 + 1.659 \times 10^{-4}\ T^3$$

$$LCF_{10} = -24.27 - 1.28722\ T + .08204\ T^2 - 1.4123 \times 10^{-3}\ T^3$$

$$LCF_{5} = -140.01 + 18.596\ T - 1.0057\ T^2 + .081\ T^3$$

$$LCF_{0} = 138.59 - 26.4097\ T + 1.39147\ T^2 - .023643\ T^3$$

$$LCF_{-5} = 90.94 - 5.76152\ T - .44056\ T^2 + .02269\ T^3$$

$$LCF_{-10} = -144.112 + 21.2597\ T + .27298\ T^2 - .132245\ T^3 + 4.0707 \times 10^{-3}\ T^4$$

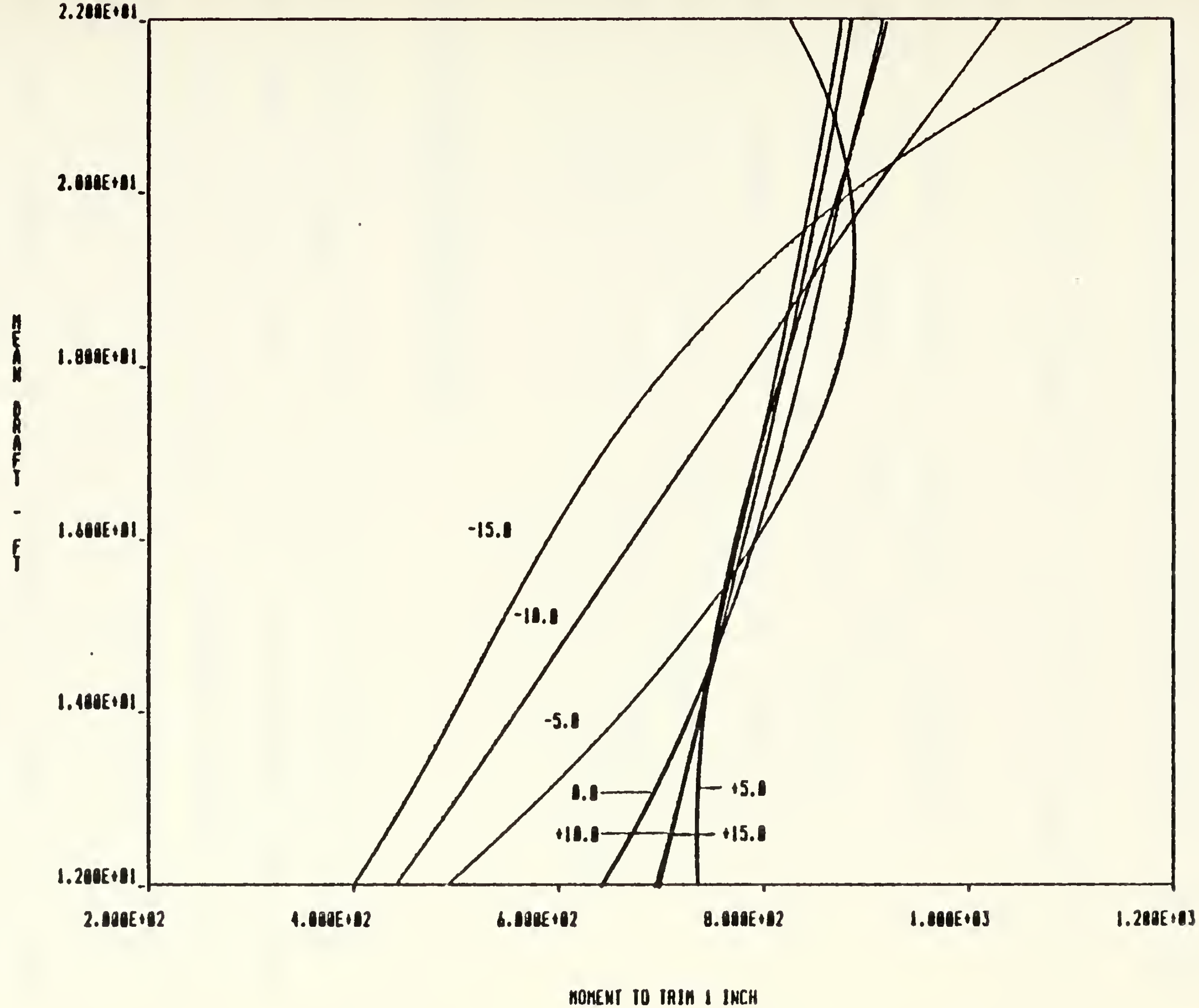
$$LCF_{-15} = 259.442 - 44.389\ T + 2.695\ T^2 - .057608\ T^3$$

2.4 MOMENT TO TRIM ONE INCH (MTI)

The hydrostatic function MTI is proportional to the displacement times the distance between the longitudinal metacenter and the center of gravity, GM_L. In addition, it is inversely proportional to the length of the ship. Figure 2.4 depicts the relationship between MTI and the mean draft for the trims investigated. Despite the obvious complexity of the relationship, the general trends may be easily described. The positive slope of the function for each trim line is due primarily to the function's dependence on displacement, the greater displacements at higher drafts insuring a steadily increasing MTI.

The quantity GM_L is equal to the longitudinal metacentric radius, BM_L, plus the height of the center of buoyancy, KG, minus the height of the center of gravity, KG. The dominant factor in this relation is the longitudinal metacentric radius, as the KB and KG terms are of the same order of magnitude and subtracted from one another. As the longitudinal metacentric radius is equal to the longitudinal moment of inertia divided by the immersed volume, the MTI is proportional to the square of the length times the beam. However, the beam is relatively constant, in the range of drafts considered, yielding a prime dependency of MTI on the square of the length. For positive trims, the length of the ship does not change substantially as the draft increases. However, for negative trims the length of the waterplane varies dramatically at low drafts due to the gradual immersion of the stern deadrise. This results in lower values of MTI for low drafts, with a much more rapid increase of the function with respect to draft.

Figure 2.4 – Mean Draft vs Moment to Trim One Inch for Trims of +/-15.0, +/-10.0, +/-5.0, and 0.0 Feet



Due to the computational scheme, described in Chapter Four, MTI is not used to determine trim as with conventional calculations. However, it is utilized to determine single compartment effects, making it an important parameter in the implementation of the damage control logic. In general, the function predicts, for forward flooding, a greater effect on trim per quantity of flooded water, particularly for light load conditions.

The MTI equations developed for the trims of interest are as follows.

$$MTI_{15} = 535.148 + 3.24361\ T + 1.221442\ T^2 - .03018687\ T^3$$

$$MTI_{10} = 466.92 + 11.9731\ T + .8994\ T^2 - .0263\ T^3$$

$$MTI_{5} = 1828.604 - 207.663\ T + 12.2996\ T^2 - .21522\ T^3$$

$$MTI_{0} = -947.846 + 240.9984\ T - 11.382415\ T^2 + .1946732\ T^3$$

$$MTI_{-5} = -851.4 + 97.34413\ T + 3.8099\ T^2 - .21681\ T^3$$

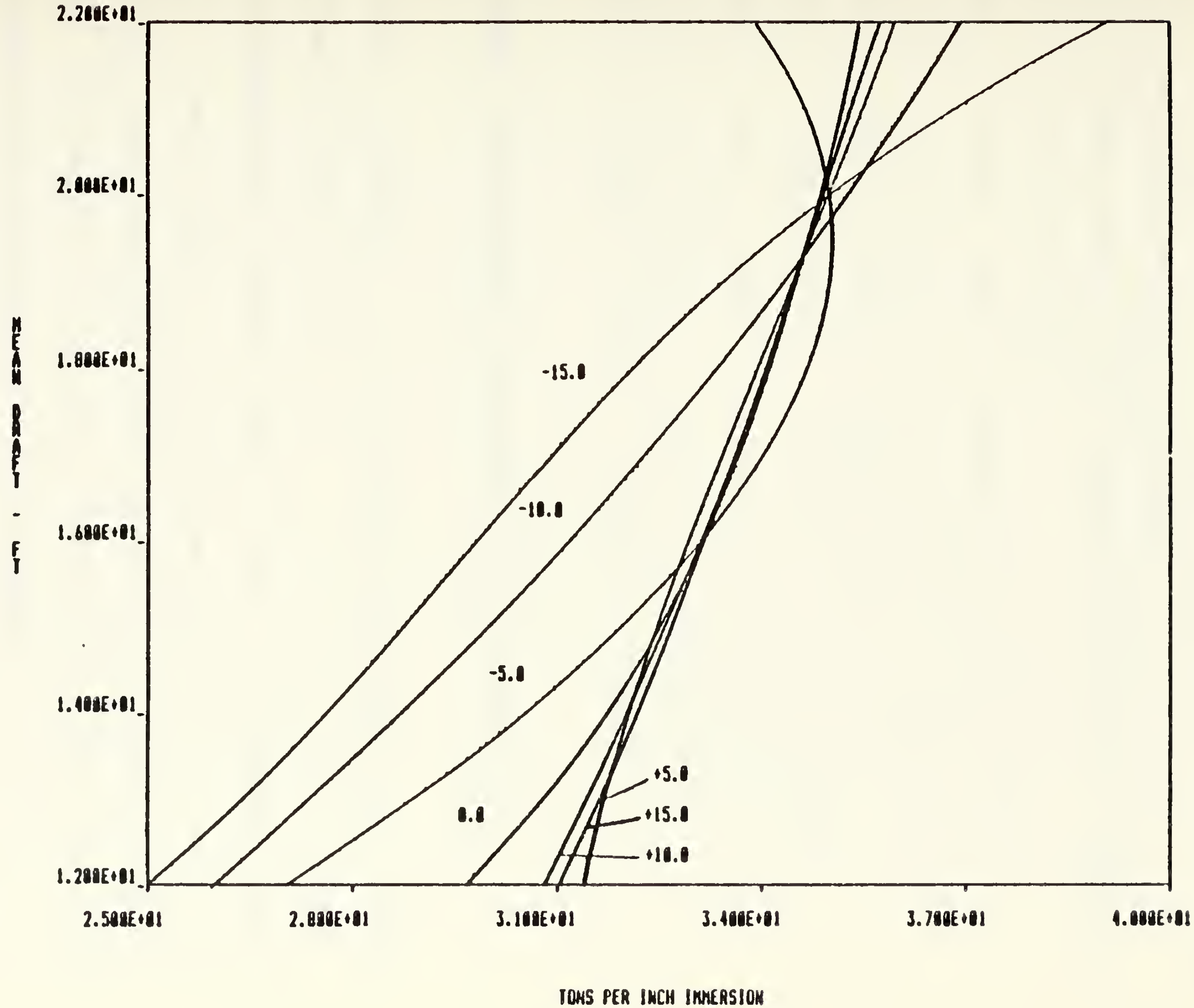
$$MTI_{-10} = -529.38 + 111.9826\ T - 3.4781\ T^2 + .07347\ T^3$$

$$MTI_{-15} = -2239.44 + 485.7155\ T - 30.67813\ T^2 + .7107294\ T^3$$

2.5 TONS PER INCH IMMERSION (TPI)

As shown in figure 2.5, TPI demonstrates the same basic trends as does MTI. TPI is proportional to the area of the waterplane and, therefore, to the length of the waterplane. The general positive slope of the function is due to the increase in the waterplane area as the draft increases. The higher slope, compared to MTI, is a result of wall-sidedness and to having no functional dependency on draft. The rapid increase in length for negative trims as draft increases is also evident in the behavior of the function.

Figure 2.5 - Mean Draft vs Tons Per Inch Immersion for Trims of +/-15.0, +/-10.0, +/-5.0, and 0.0 Feet



TPI is utilized in the program to determine single compartment effects. Although there are only small deviations from the zero trim case for positive trims, negative trims possess significantly lower values of TPI. When coupled with the lower values of MTI for these trims, this effect can significantly alter the final flooded state for damage to the forward portions of the ship.

The following equations were determined for TPI as a function of draft for the trims of interest.

$$TPI_{15} = 18.203 + 1.6673\ T - .0623975\ T^2 + 1.039 \times 10^{-3}\ T^3$$

$$TPI_{10} = 24.374 + .3121\ T + 3.07 \times 10^{-2}\ T^2 - 1.0013 \times 10^{-3}\ T^3$$

$$TPI_{5} = 36.524 - 1.4008\ T + .1028\ T^2 - 1.83 \times 10^{-3}\ T^3$$

$$TPI_{0} = -11.853 + 6.3978\ T - .308423\ T^2 + 5.2717 \times 10^{-3}\ T^3$$

$$TPI_{-5} = -1.877 + 2.3611\ T - .04909\ T^2 - 3.75 \times 10^{-3}\ T^3$$

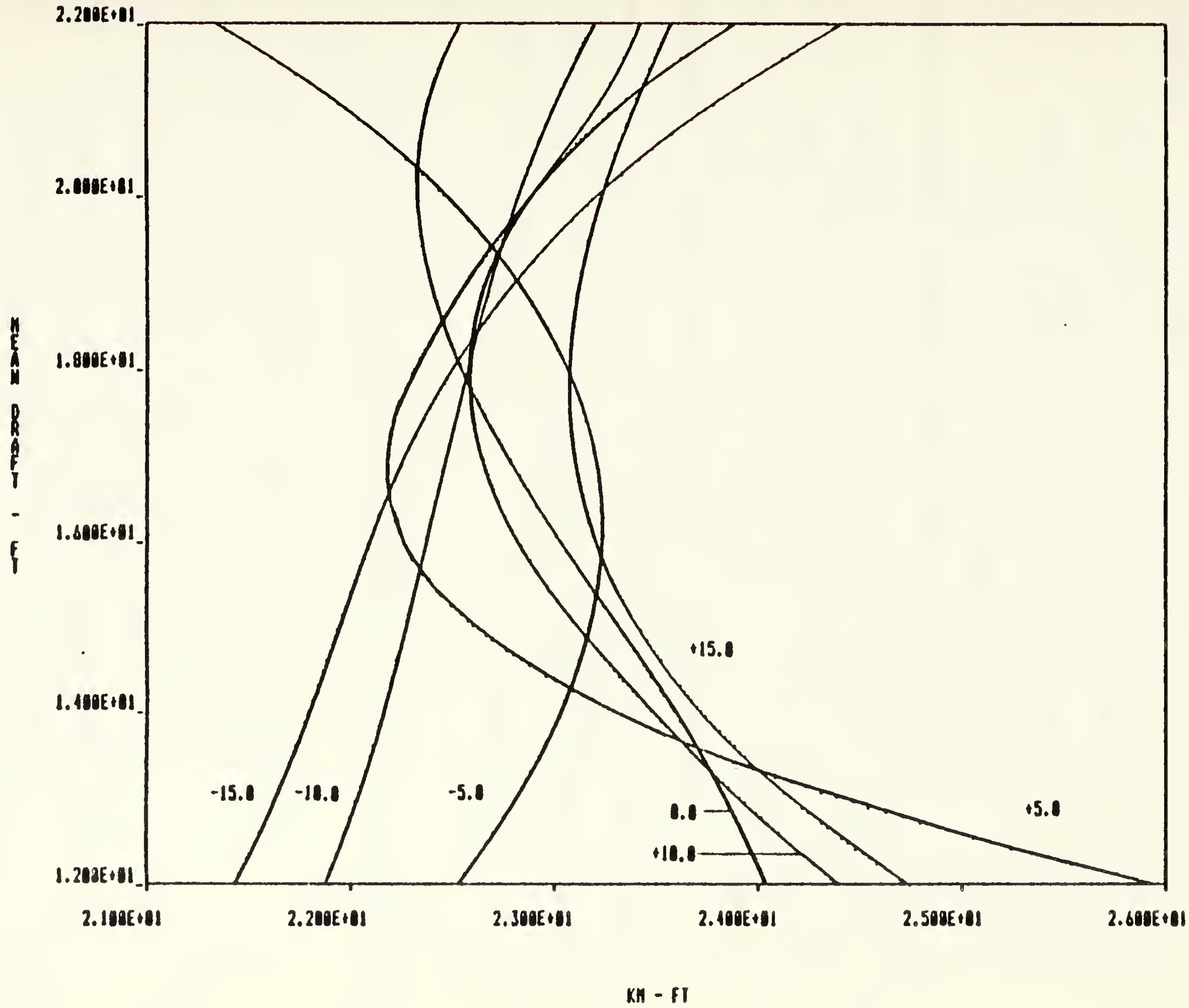
$$TPI_{-10} = .639 + 2.8305\ T - .067871\ T^2 + 6.44036 \times 10^{-4}\ T^3$$

$$TPI_{-15} = -28.698 + 9.01801\ T - .50905\ T^2 + .0108721\ T^3$$

2.6 HEIGHT OF THE TRANSVERSE METACENTER ABOVE THE KEEL (KM_T)

Figure 2.6 depicts the relationship between mean draft and the transverse metacentric height, KM_T. As can be seen, this function is not well-behaved and analysis does not lead to any general trends of behavior. However, KM_T is an important parameter as it is used to calculate GM_T, the accepted first-order measure of transverse stability. Therefore, KM_T should be calculated as accurately as possible to provide the operator with the best value of GM_T available.

Figure 2.6 - Mean Draft vs Height of Transverse Metacenter Above the Keel for Trims of +/-15.0, +/-10.0, +/-5.0, and 0.0 Feet



KM_T is equal to the sum of the metacentric radius, BM_T, and the height of the center of buoyancy, KB. BM_T is equal to the transverse moment of inertia of the waterplane divided by the immersed volume, making BM_T proportional to the square of the beam over the draft. Due to the wall-sidedness of the ship, the beam remains relatively constant. This results in a first-order dependency of BM_T on the inverse of the draft. Therefore, as the draft increases, BM_T decreases. On the other hand, KB is directly proportional to the draft, causing an increase in KB with draft. Noting that each of these terms are of the same order of magnitude and display opposite trends with increasing draft, sheds light on the unpredictable behavior of the function. For a given trim, the function is very sensitive to the relative slopes of its two factors, yielding the erratic behavior shown in figure 2.6. The differences in the function for various trims arise from second-order effects caused by trim and are not easily predicted. However, it should be noted that in the draft range of sixteen to nineteen feet, the most common mean drafts after damage, the variance in KM_T is less than ten percent over all trim cases.

The following relations were developed for KM_T as a function of mean draft.

$$KM_{15} = 47.2044 - 3.41579\ T + .155151\ T^2 - 2.215 \times 10^{-3}\ T^3$$

$$KM_{10} = 27.36 + .4337\ T - .0927\ T^2 + 2.9915 \times 10^{-3}\ T^3$$

$$KM_5 = 108.11 - 13.54116\ T + .6988\ T^2 - .01174\ T^3$$

$$KM_0 = 14.923 + 2.22534\ T - .166143\ T^2 + 3.669 \times 10^{-3}\ T^3$$

$$KM_{-5} = 17.07 + .3843\ T + .023161\ T^2 - 1.446 \times 10^{-3}\ T^3$$

$$KM_{-10} = 14.987 + 1.1651\ T - .065201\ T^2 + 1.327 \times 10^{-3}\ T^3$$

$$KM_{-15} = 6.843 + 2.7624\ T - .176611\ T^2 + 3.9704 \times 10^{-3}\ T^3$$

2.7 FREE SURFACE EFFECT - POCKETING

The effect of a tank partially full of liquid on the stability of a ship is known as the free surface effect. As the ship is inclined, the liquid in the tank, and consequently the center of gravity of the liquid, shifts to the low side resulting in a shift of the ship's center of gravity in the same direction. This motion causes a reduction in the righting arm, and hence, stability. The shift in the ship's center of gravity is calculated by dividing the transverse weight moment of the liquid by the displacement of the ship. The weight moment of the liquid is known as the moment of transference and is equal to the apparent reduction in the KG of the ship as a result of the loss of righting arm. This virtual lowering of the center of gravity is called the free surface effect and is equal to the transverse moment of inertia of the liquid's free surface divided by the specific gravity of the liquid times the sine of the angle of inclination. In the case of multiple tank effects, normally the effect of each tank is calculated and summed to yield the total reduction in the height of the center of gravity.

When the tank is almost full, or empty, the effect of the motion of the liquid is reduced somewhat by the free surface intersecting the top or bottom of the tank. This reduces the horizontal and vertical shifts of the liquid's center of gravity, and, therefore, the free surface effect. For these cases, the sine term is replaced by the Factor for Moment of Transference, which includes the dependence on heel and a dependence on the depth to breadth ratio of the tank. These factors are identical for a tank that is a given percentage full or empty; i.e., the

factor for a tank with a depth to breadth ratio of 1.0 for a ten degree heel is the same for both the 95 percent and 5 percent full cases.

Guidance for the use of the Factors for Moment of Transference is found in the Principles of Naval Architecture [1]. A practical degree of accuracy using the sine relationship can be obtained when the total moment of inertia of all partially filled tanks in $feet^4$ is not more than 20 times the displacement in tons. When the total moment of inertia is more than this criterion, the moments of transference for each tank should be calculated. For the FFG-7, in an intact condition, the total moment of inertia of the free surfaces is never greater than fourteen times the displacement. In the damaged case, although this total would be well above the criterion, the program logic would require substantial modifications to provide for such accounting. As a conservative stability estimate is produced from this omission, the free surface correction for pocketing is not presently included in the Stability Module.

However, for larger ships with more free surface, this effect would have to be included. Appendix C details the derivation of the Factors for Moment of Transference for a 95 percent full tank.

2.8 CONCLUSION ON TRIM EFFECTS

As can be seen in the previous sections, the key hydrostatic parameters of LCB, LCF, MTI, TPI, and KM vary with the trim of the ship. This dependence manifests itself as changes in the parameters for various trims at a constant displacement. As flooding can cause a wide

range of trim conditions, these parameters must be expressed as functions of trim as they are used to determine the hydrostatic state of the ship. In addition, these quantities are used to predict the effects of the flooding of single compartments, a key factor of the Damage Control Logic. Therefore, the accuracy of these quantities is critically important if the Module is to provide the operator with the best prediction of the ship's state.

3.0 STABILITY CURVES AS A FUNCTION OF TRIM

The stability characteristics of a ship are based on the curves of static stability, the plot of righting arm versus angle of inclination for a given displacement. Static parameters such as metacentric height, angle of maximum righting arm, and range of loll can be read directly from the static stability curve, once corrections for center of gravity position, off-center weights, free surface effect, and wind conditions are applied. Dynamic considerations to stability, such as the ship's ability to survive the motions of rolls, are determined from an investigation of various areas under the righting arm curve, as described by Sarchin and Goldberg [9]. The module creates the curve of static stability by means of the Fourier harmonic analysis described by LT Sander [8] from data from the input cross curves of stability. The cross curves of stability are a family of curves of righting arm as a function of displacement for constant angles of inclination. Therefore, it is critically important to provide the best input cross curves; so that the output parameters will predict the ship's stability as accurately as possible.

The cross curves of stability for a ship are determined by calculating the horizontal distance between the centers of buoyancy and gravity, or righting arm, through a desired rnage of displacements. The common practice is to generate a curve for every ten degrees of inclination up to ninety degrees of heel. The cross curves are, therefore, strong functions of the underwater hullform; which, as demonstrated in Chapter Two, can vary significantly with trim. In order to provide the

most accurate analysis of the static and dynamic stability characteristics, the cross curves of stability should be implemented as functions of trim.

3.1 METHOD OF GENERATION AND PRESENTATION OF DATA

As with the hydrostatic parameters, the data required to define the cross curves was provided by the program 'SHCP.' For the cross curves, trims of 15.0, 7.5, 0.0, -7.5, and -15.0 feet were chosen. This distribution of trims allows for the minimum number of trim lines to cover the range desired and still provide for accurate linear interpolation. The data from 'SHCP' provided the data for ten to eighty degrees, and the ninety degree cross curve was determined by extrapolation of selected static stability curves. Each cross curve was expressed, by a last-squares fit, as a third or fourth order polynomial in displacement. The curve fits possessed excellent correlation to the data. The equations generated by this method are located in Appendix D. Figures 3.1 through 3.5 graphically depict the cross curves of stability for the trims investigated.

3.2 SIGNIFICANCE OF TRIM EFFECTS ON STABILITY

Although figures 3.1 through 3.5 demonstrate variances of the cross curves for different trims, the trends describing these variances are not readily apparent. Figures 3.6 through 3.8 are the static stability curves derived from the cross curve data for displacements of 3000, 4000, and 5000 tons, respectively. This range of displacement covers

Figure 3.1 - Cross Curves of Stability
for a Trim of 15.0 Feet

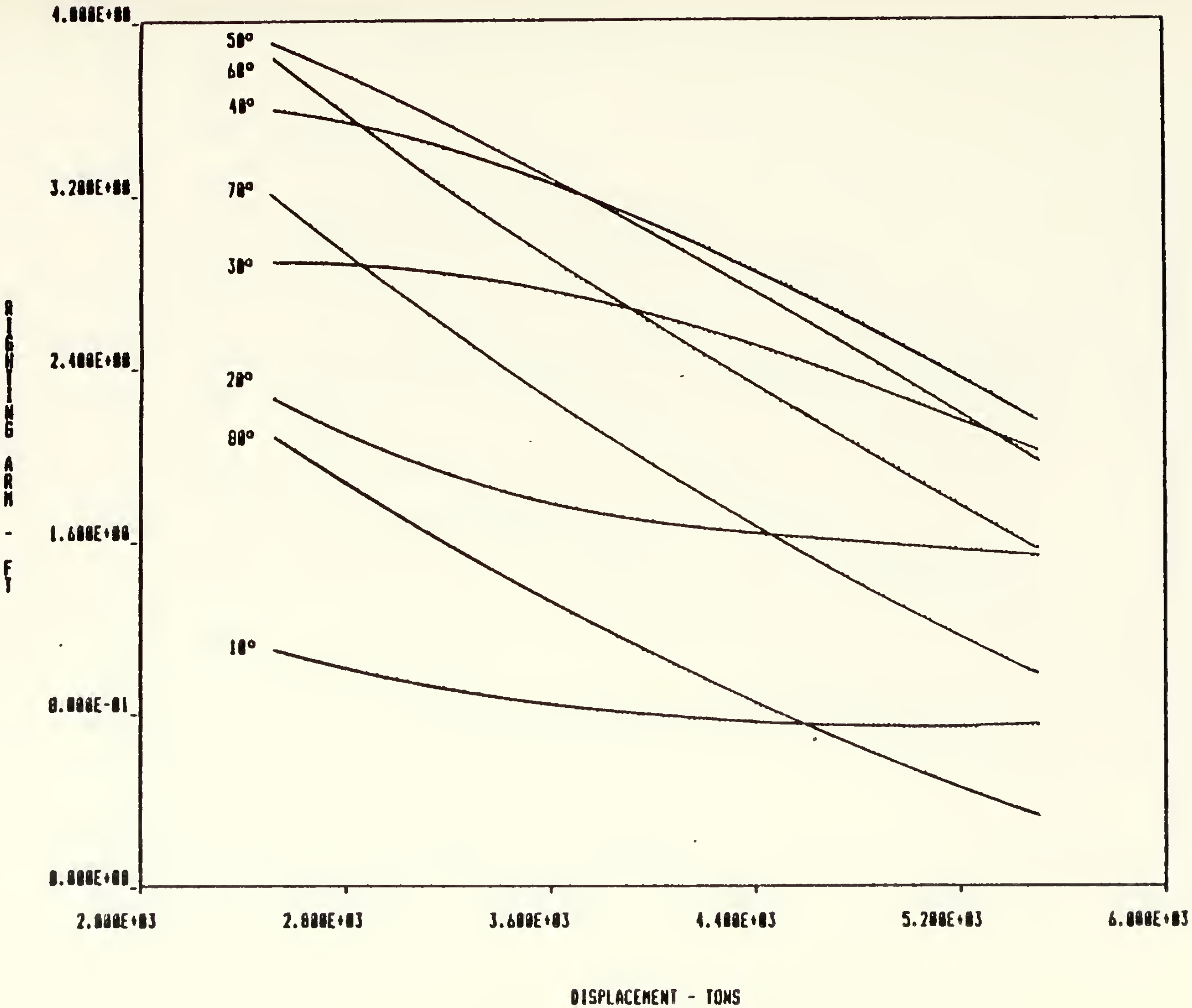


Figure 3.2 - Cross Curves of Stability
for a Trim of 7.5 Feet

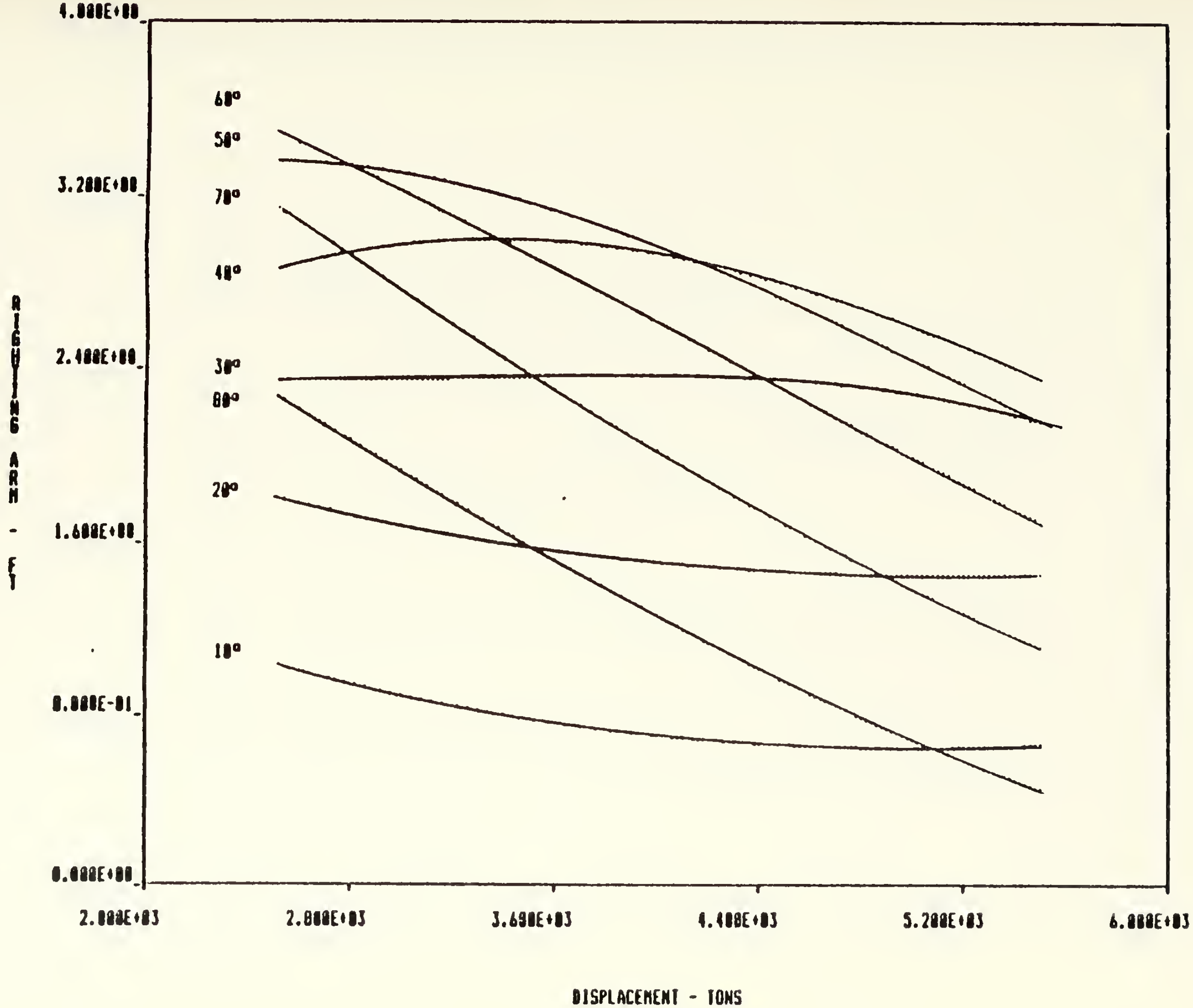


Figure 3.3 - Cross Curves of Stability
for a Trim of 0.0 Feet

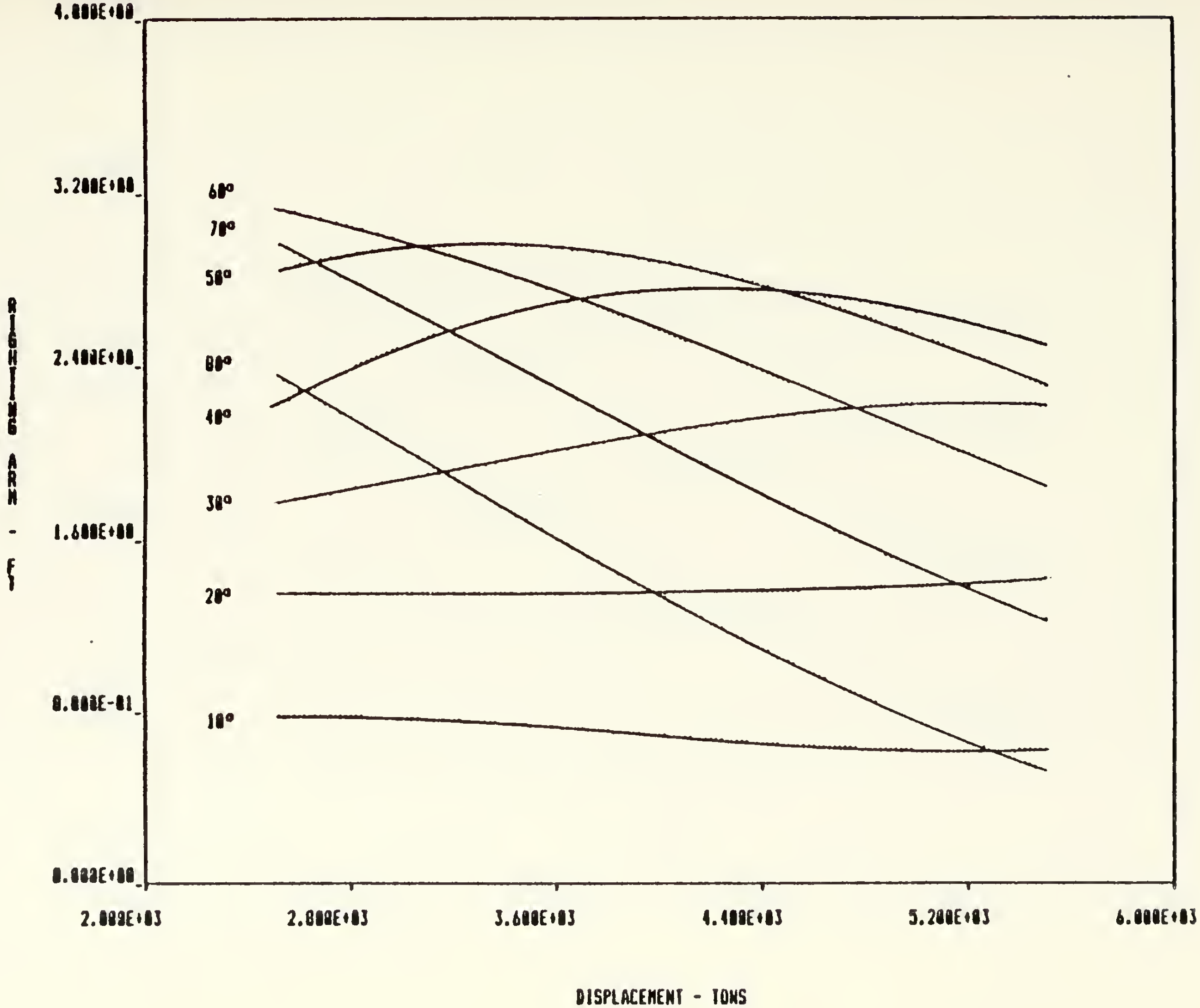


Figure 3.4 - Cross Curves of Stability for a Trim of Negative 7.5 Feet

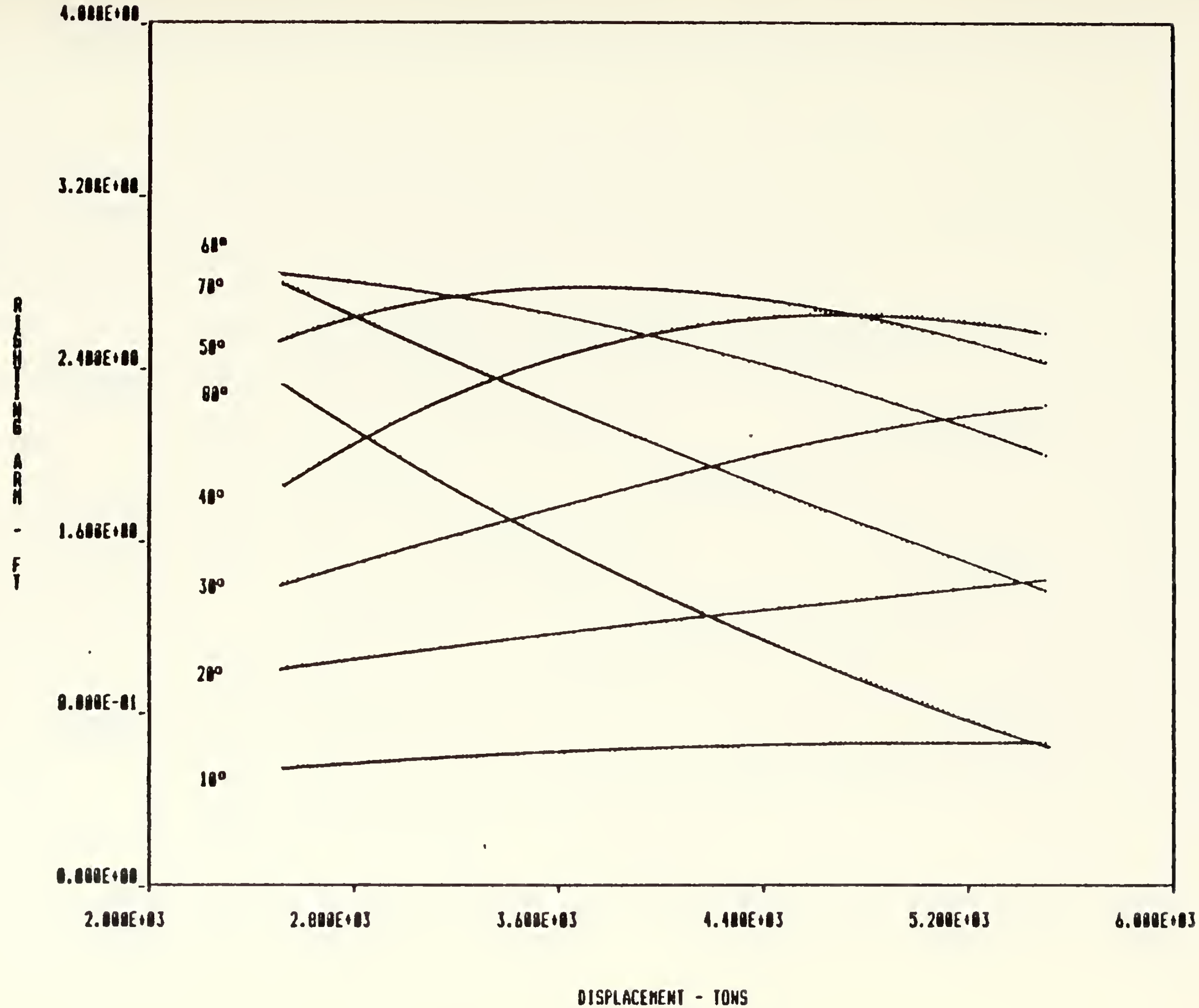
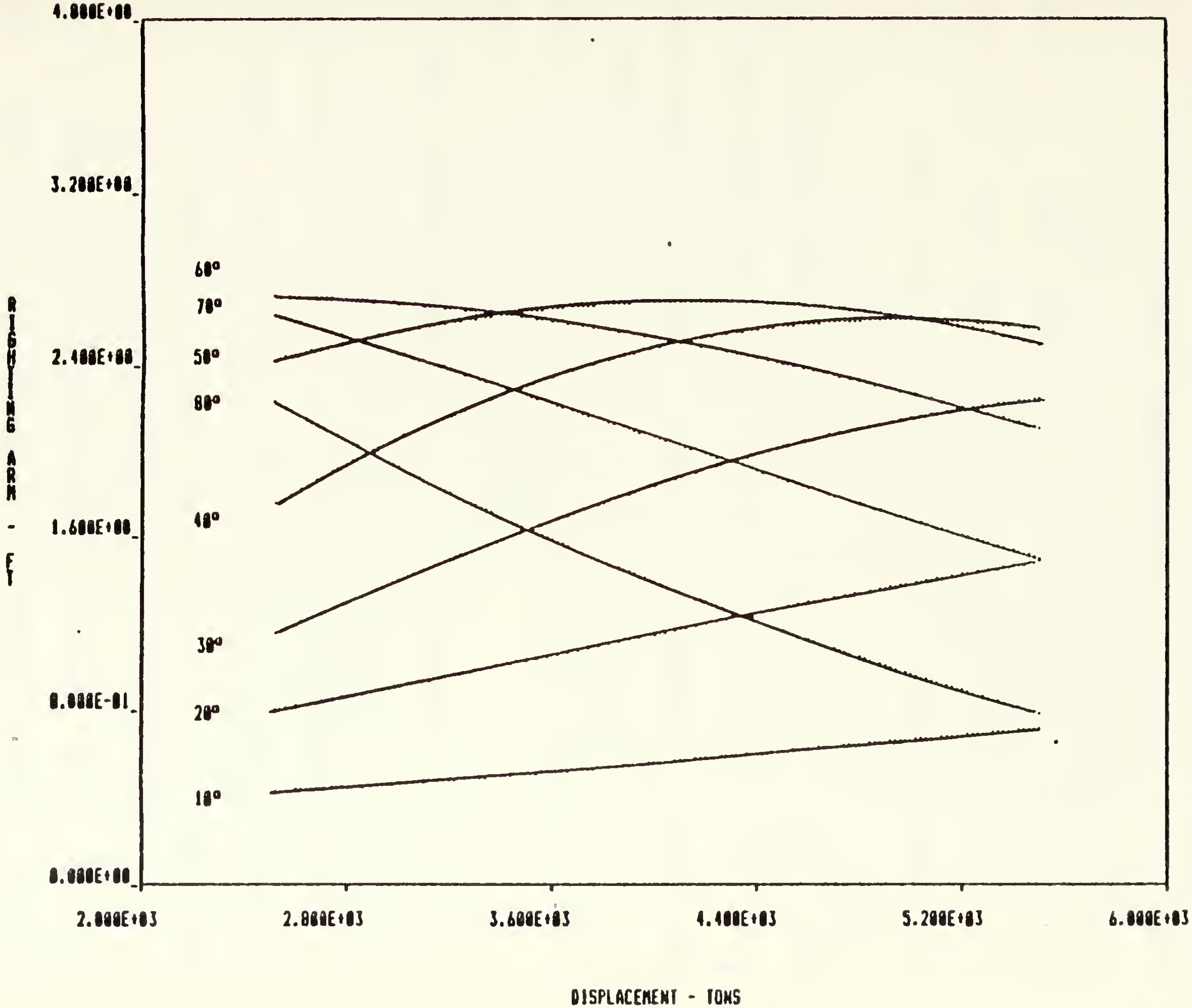


Figure 3.5 – Cross Curves of Stability for a Trim of Negative 15.0 Feet



the minimum and maximum loading conditions for the FFG-7. From these plots, the significance of trim on various stability parameters may be investigated.

Standard stability calculations, based on the zero trim righting arm curve, lead to a constant angle of list for an off-center weight, regardless of where it is placed longitudinally on the ship. The static stability curve is adjusted for an off-center weight condition by the subtraction of a cosine curve with a maximum ordinate equal to the transverse shift in the center of gravity due to the weight. The intersection of this curve with the curve of static stability defines the angle of list the ship will experience due to the off-center weight. For static stability curves plotted for various trims, it can be shown that the wieght correction curve will intersect the positive trim curves before the negative trim curves. This causes a smaller heel angle than normally predicted for the stern down case, and the opposite effect for the bow down case. This effect is most pronounced for light loading conditions, less than 3500 tons displacement.

An example serves to point out the significance of this effect. For an off-center weight added at the stern of the ship, a positive trim will develop and the list angle will be less than that predicted by conventional methods. If this added weight is water in free communication with the sea, the iterative technique used to determine the final angle of heel will converge to a smaller angle than the conventional method as less water is allowed into the hull in each iteration step. The opposite effect would occur with asymmetrical flooding forward. Calculations have shown this difference in heel angle to approach ten percent

Figure 3.6 – Static Stability Curve for 3000 Tons
for Trims of +/-15.0, +/-7.5, and 0.0 Feet
Assumed KG = 19.0 Feet

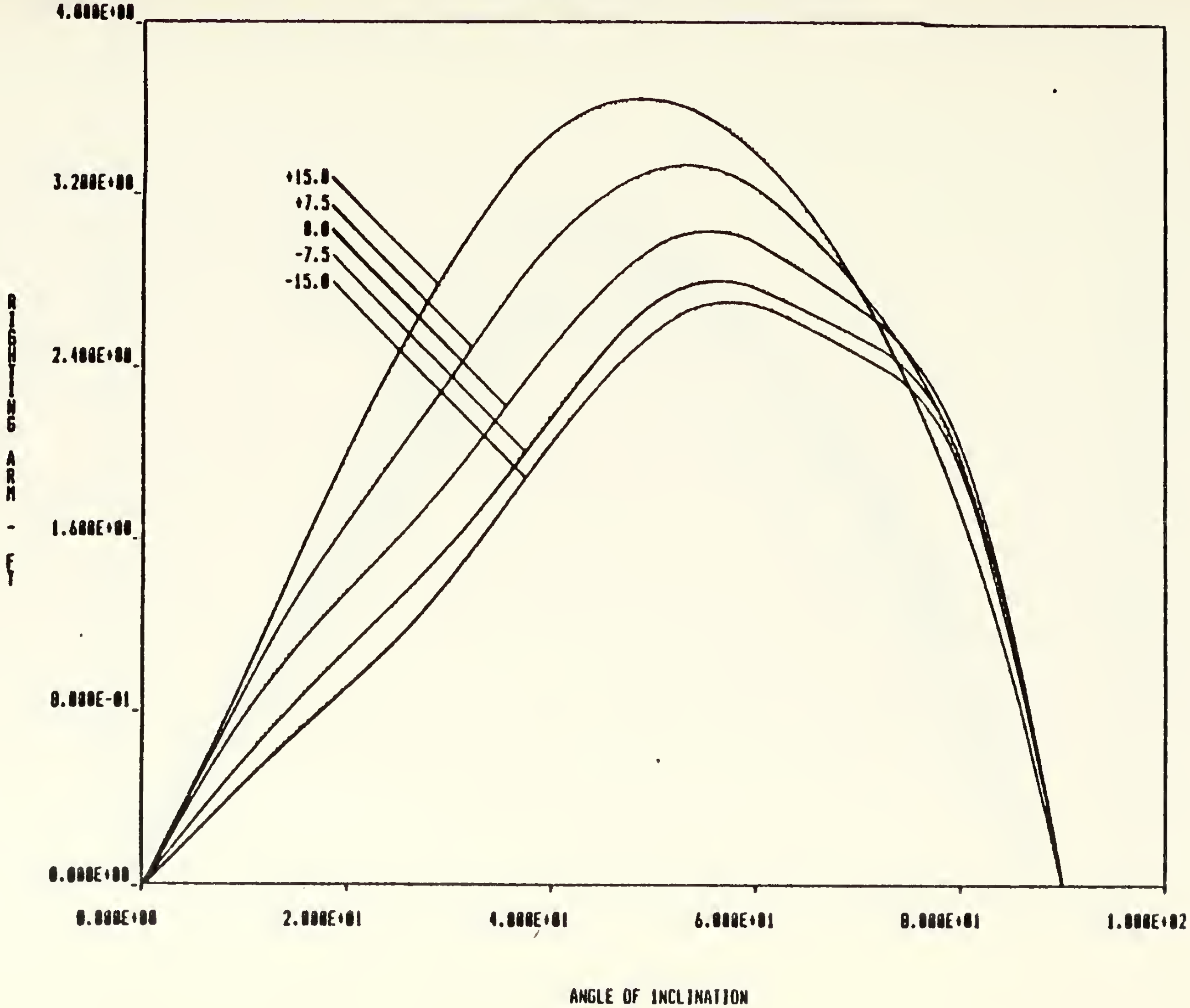


Figure 3.7 - Static Stability Curve for 4000 Tons for Trims of +/-15.0, +/-7.5, and 0.0 Feet Assumed KG = 19.0 Feet

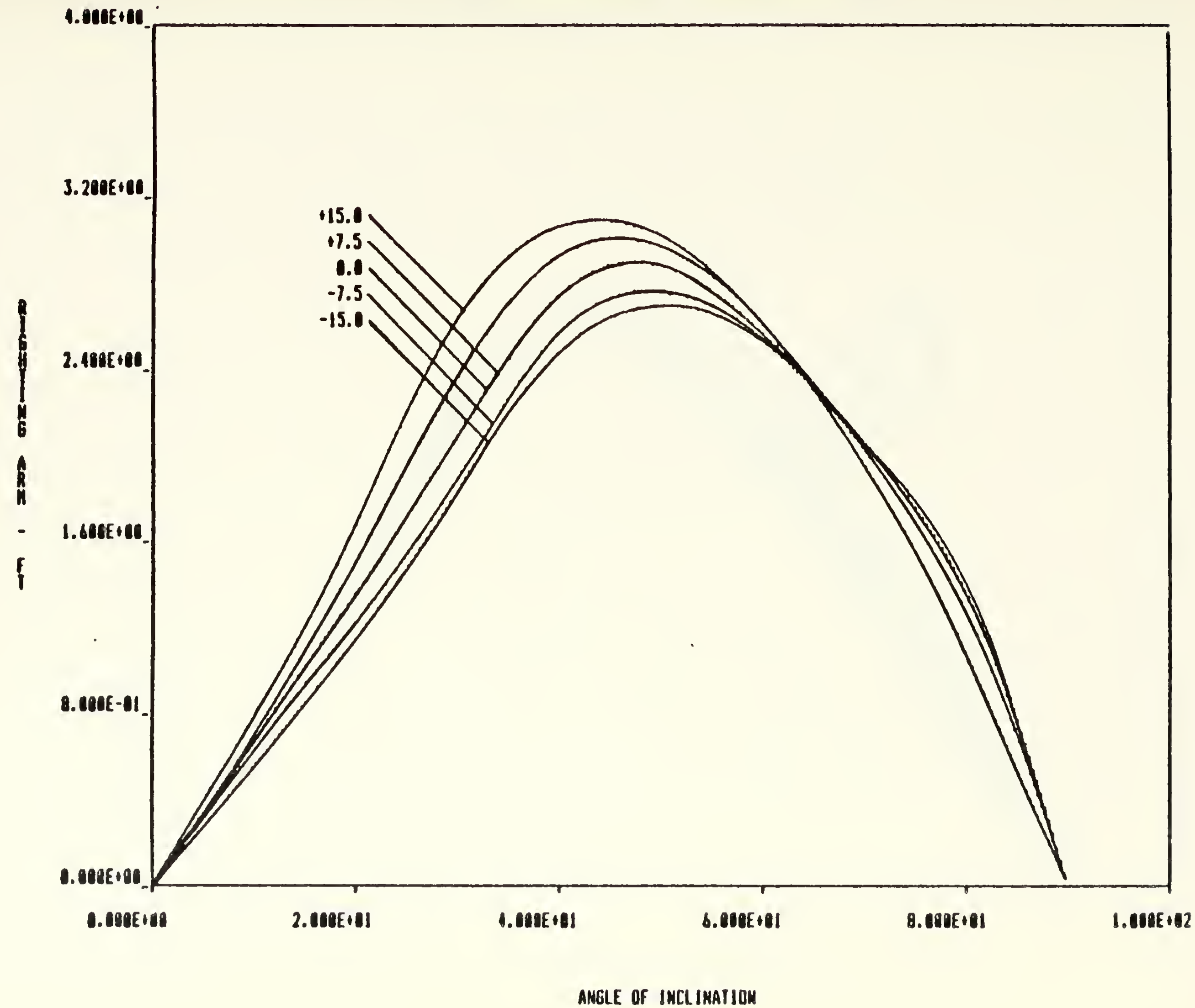
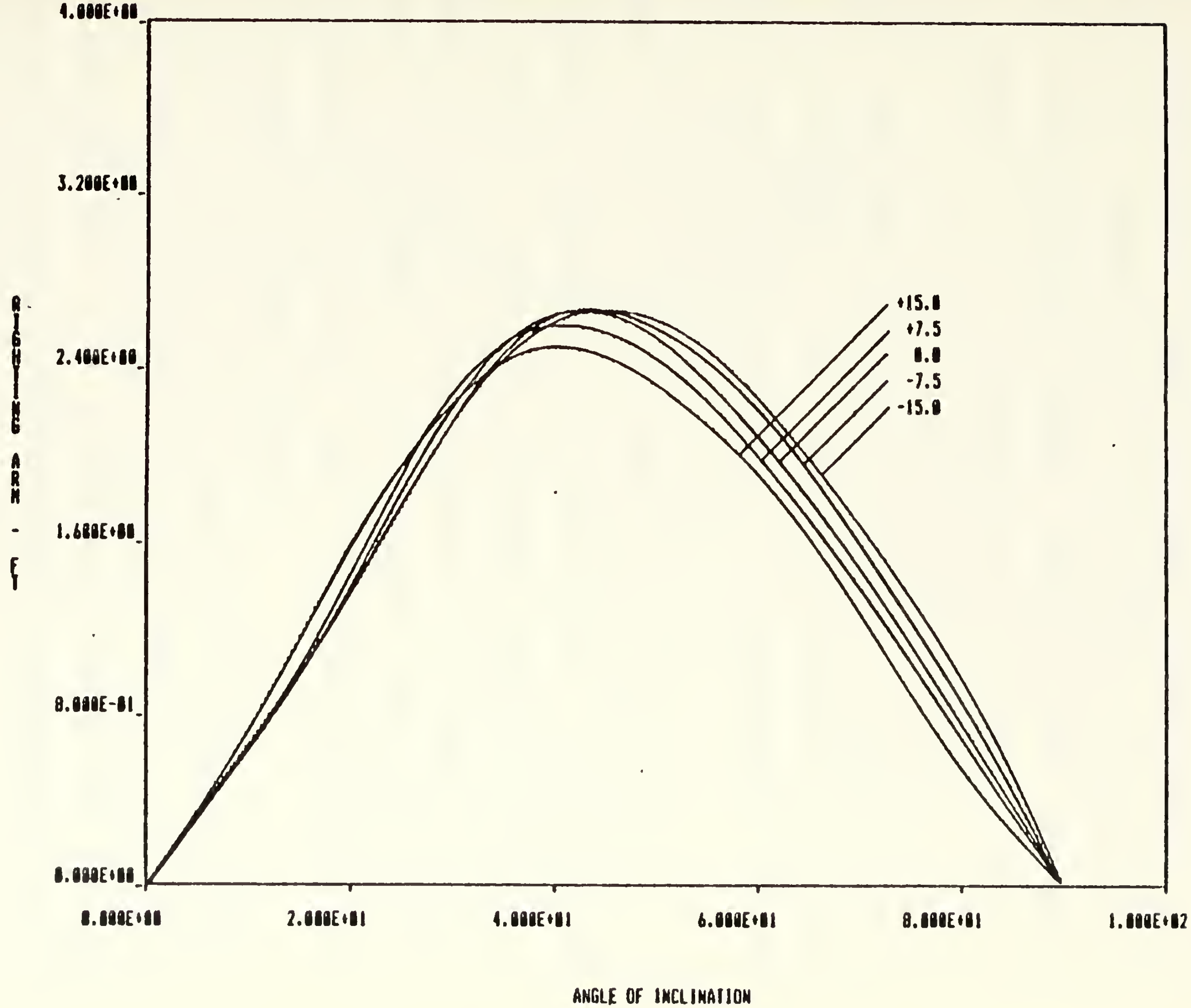


Figure 3.8 - Static Stability Curve for 5000 Tons for Trims of +/-15.0, +/-7.5, and 0.0 Feet
Assumed KG = 19.0 Feet



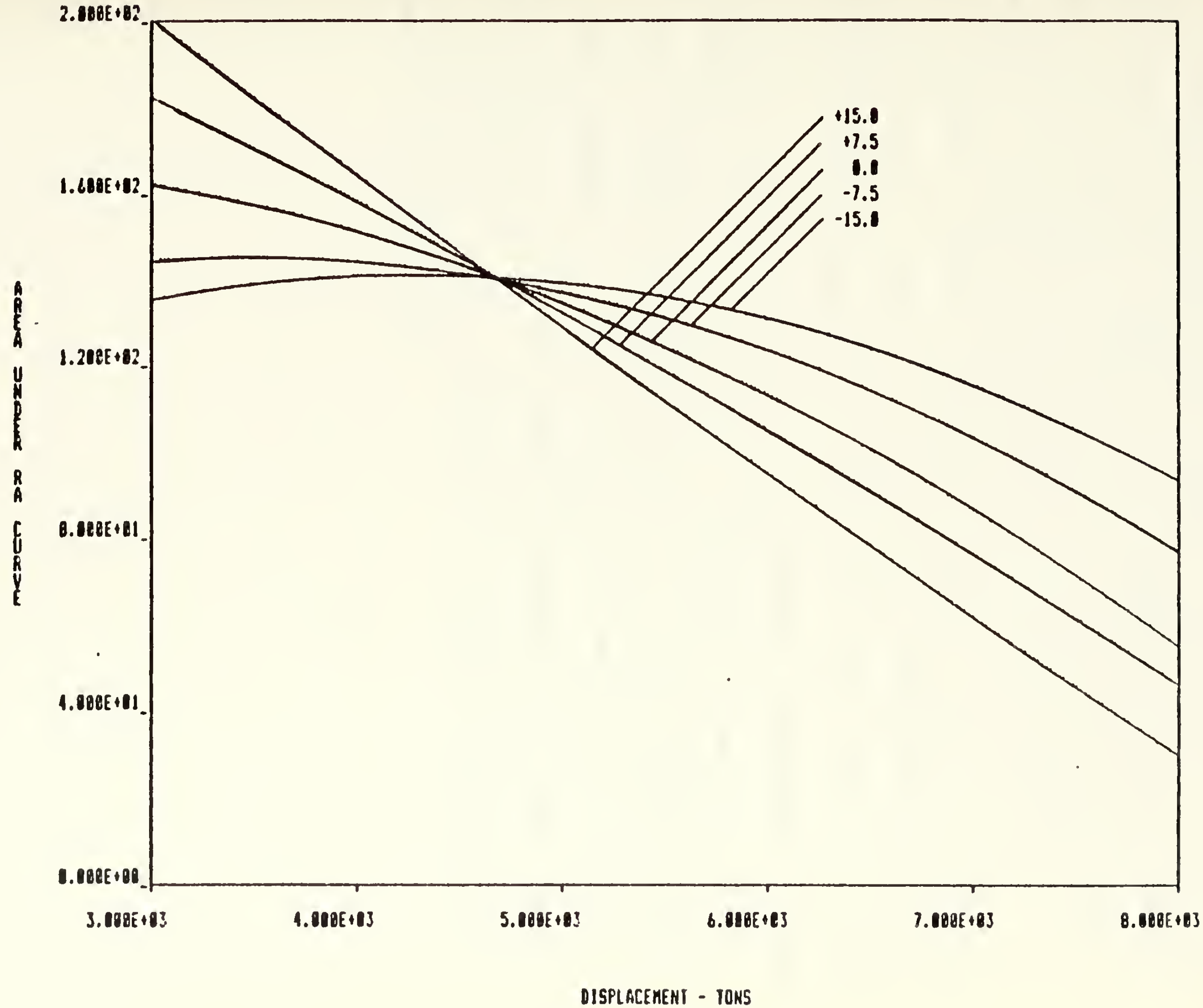
of the heel predicted by standard calculations. Although not numerically significant, this angle is also used to determine the free surface and wind heeling correction factors. Therefore, the effect is additive at several levels of calculation, and should be accounted for.

Also, in this range of displacement, the negative trim conditions display a greater angle at which the maximum righting arm occurs over positive trims. However, for low displacements, the positive trims possess a numerically greater maximum righting arm than the negative trims. Therefore, it is not immediately clear whether positive or negative trims possess better stability characteristics. This is especially true as the trends appear to reverse at approximately 4500 tons. This inability to deduce the relative behavior of the static stability curves for various trims leads to an investigation of the area under the righting arm curve as a function of trim.

Figure 3.9 is a plot of the area under the static stability curve as a function of displacement for various trims. As previously mentioned, this area is a measure of the dynamic stability of the ship, as it represents the energy the ship possesses to withstand roll motions. Consequently, this parameter is very important in determining the overall stability state of the ship. Figure 3.9 characterizes several noteworthy trim effects on dynamic stability.

In general, dynamic stability decreases with increasing displacement. Additionally, this trend is more significant for positive trims than for negative trims. It is interesting to note that this reduction in the ability of the ship to withstand damage is compounded by the loss of freeboard in high displacement conditions.

Figure 3.9 – Area Under the Righting Arm Curve vs Displacement for Trims of +/-15.0, +/-7.5, and 0.0 Feet



The most important effect depicted in figure 3.9 is the effect of trim on the relative areas at a given displacement. Below approximately 4600 tons, positive trims possess better dynamic stability characteristics than negative trims. For displacements greater than 4600 tons, the trend is reversed yielding better stability states for bow down trims. The significance of this effect is that, depending on the trim and displacement, the stability criteria utilized by the program may under or over estimate the areas in question based on the zero trim line.

For example, for severe flooding forward of a ship in the minimum operating condition, a trim of -5.0 feet and a displacement of 4000 tons are the approximate values of the ship's state after damage. The total area under the righting arm curve is approximately ten percent less than that predicted by the zero trim case. Therefore, in heavy beam seas and high wind conditions the ship may well be in a more critical stability state than predicted. As the purpose of the module is to provide the operator with the best possible stability analysis, but always conservative in estimates, this trim effect on dynamic stability must be included in the program logic.

4.0 IMPLEMENTATION OF TRIM DEPENDENT HYDROSTATIC AND STABILITY PARAMETERS INTO THE STABILITY MODULE

The introduction of trim effects on the hydrostatic and stability parameters that define the ship's state requires a modification of the calculation algorithms used by the module. Appendix E contains the listings of the subroutines modified as a result of this inclusion. A description of the algorithms utilized in these subroutines is detailed below to provide the required documentation.

4.1 HYDROSTATICS

As hydrostatic parameters are now expressed for various trims, the standard calculation technique utilized to determine the hydrostatics of the ship can not be used. The trim of the ship must now be set prior to the calculation of the hydrostatic parameters, such as LCF, KM, MTI, and TPI. In addition, interpolation is required to determine these quantities at the given trim from the known quantities at the bounding trims. Therefore, a sufficiently accurate interpolation scheme must be chosen.

Figures 4.1 through 4.5 show the relationships between the key hydrostatic parameters and trim. Although these curves are for only one mean draft, sixteen feet, an investigation of other drafts yields results similar to the following analysis. The functions of LCB, LCF, and TPI are characterized by mild curvatures; and excellent correlation exists between the curves and linear interpolation between successive five foot trim lines. The functions defining KM and MTI are not as

Figure 4.1 - LCB vs Trim
Draft = 16.0 Feet

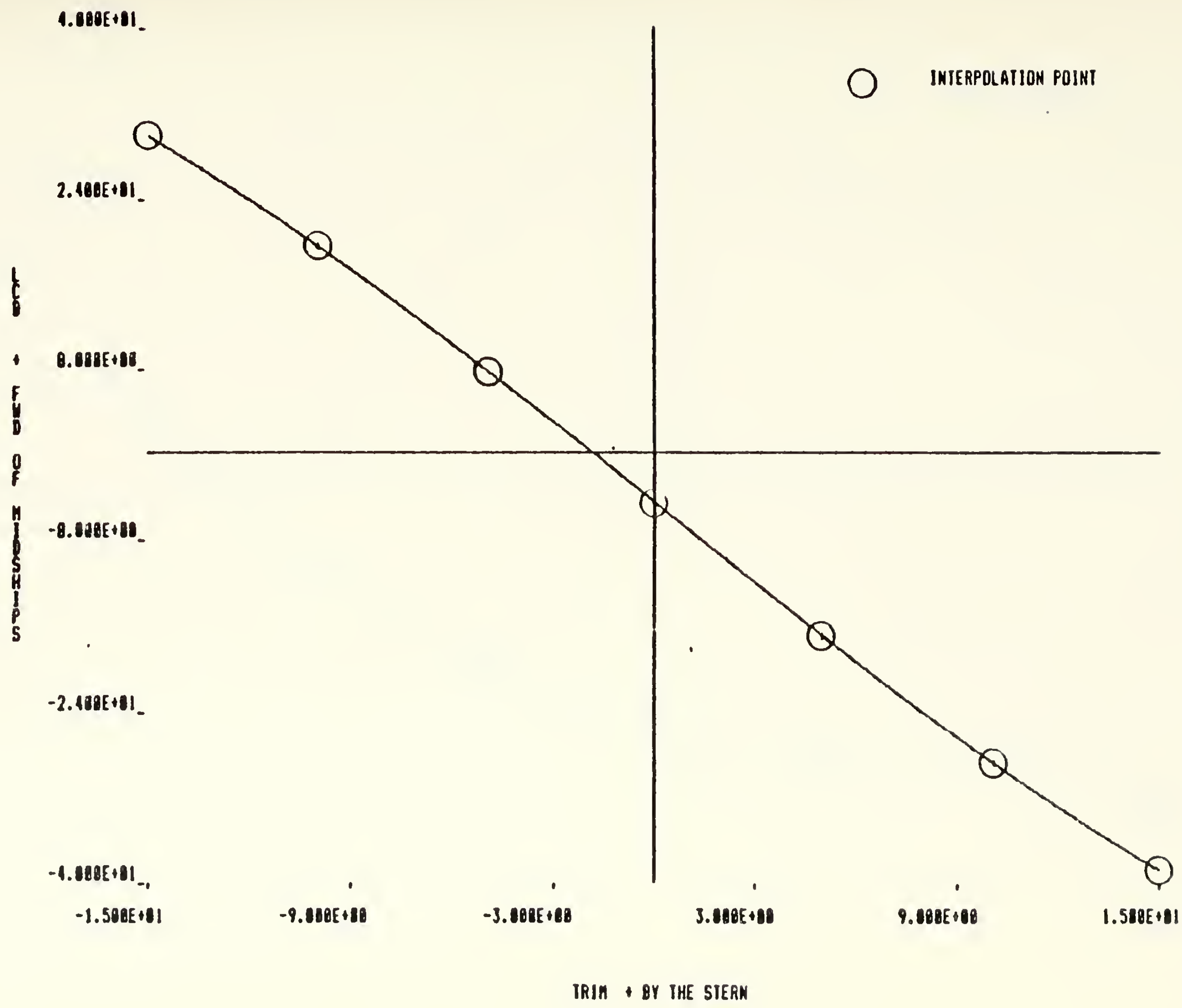


Figure 4.2 - LCF vs Trim
Draft = 16.0 Feet

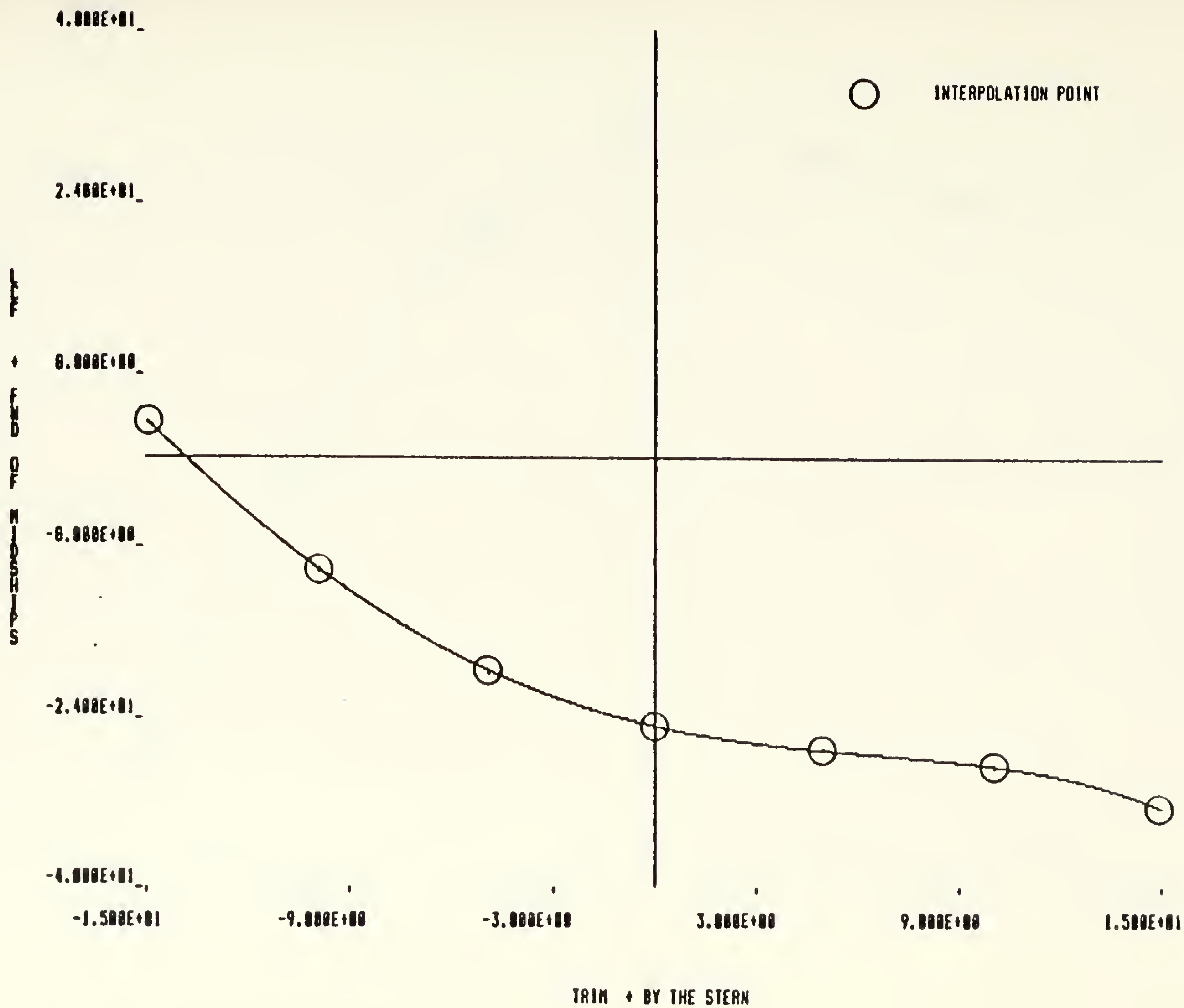


Figure 4.3 - Tons Per Inch Immersion vs Trim
Draft = 16.0 Feet

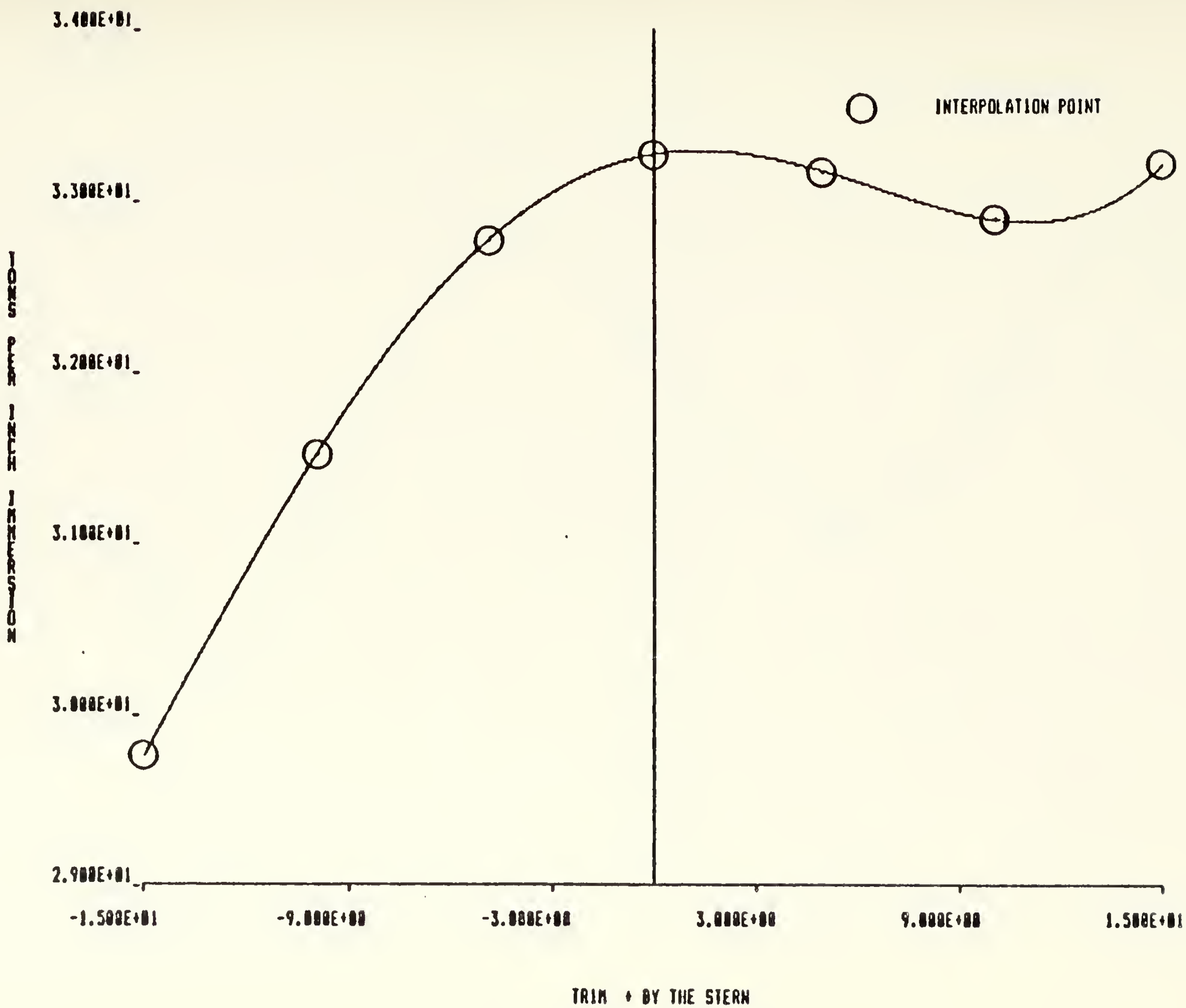


Figure 4.4 - KM vs Trim
Draft = 16.0 Feet

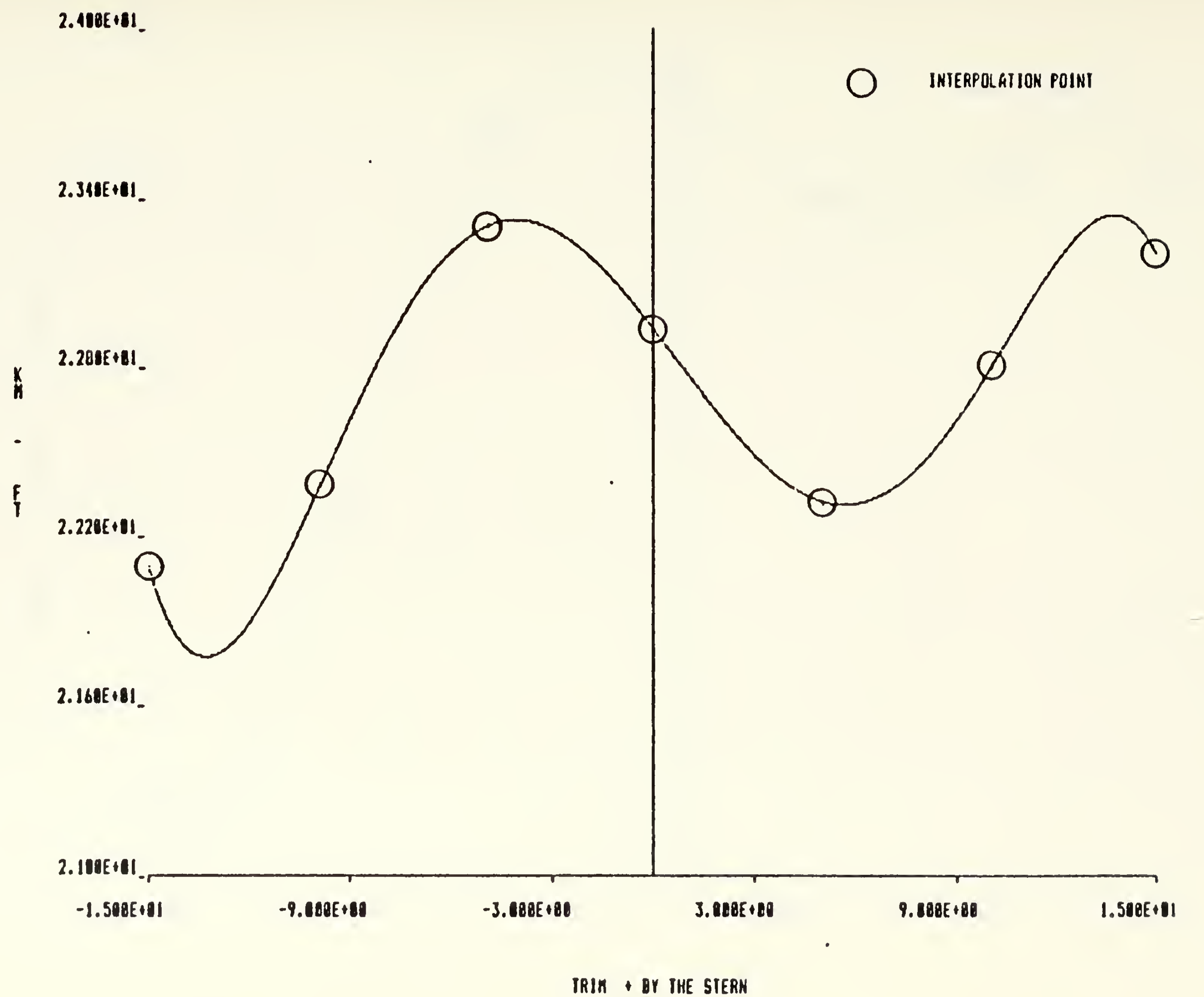
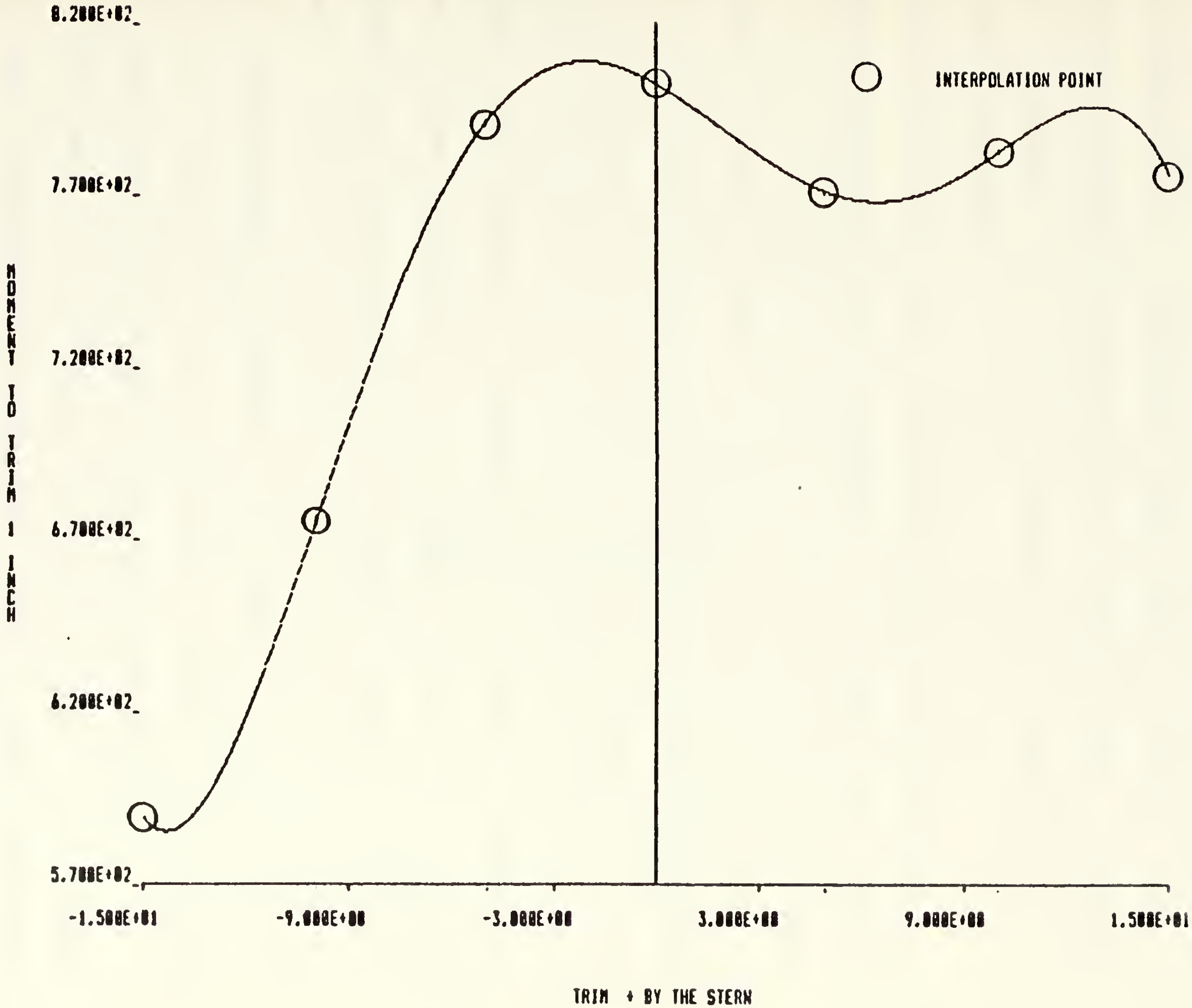


Figure 4.5 - Moment to Trim One Inch vs Trim
Draft = 16.0 Feet



well-behaved and interpolation between 5 foot trim lines introduces errors into the calculation effort. For the sixteen foot mean draft case, the maximum errors are five and two percent for MTI and KM, respectively. Although this is reasonably good accuracy, second and third order interpolation techniques were investigated. These schemes did not demonstrate a significant improvement in accuracy over the linear case to justify the additional computational effort. Therefore, linear interpolation is utilized throughout the computation of the hydrostatic parameters.

As mentioned, the trim of the ship must be defined before the hydrostatic parameters can be calculated. To achieve this, the mean draft at each trim line is calculated from the input displacement. Then, the LCB for each trim is calculated from the appropriate mean draft. As the ship will trim until the LCB and the LCG are coincident, the LCG is compared to the calculated LCB's at each trim until it is bracketed. The trim is then determined by linear interpolation. For this trim, each hydrostatic parameter is calculated by interpolating between the known quantities at the bounding trims. The forward and after drafts are then calculated as in standard methods utilizing the mean draft, trim, and LCF parameters. In the case of the trim exceeding 15 feet, the hydrostatic parameters corresponding to the appropriate 15 foot trim line are used for all calculations. However, this situation did not occur at any time during the running of the program.

To demonstrate the differences between the outputs of the conventional method of hydrostatic calculations and algorithms incorporating trim effects, Table 4.1 has been prepared to compare the parameters for

both techniques. The base ship condition is the minimum operating condition, with one-third stores and fuel remaining. A weight of 500 tons was placed on centerline, ten feet above the baseline, and 350 feet aft of the forward perpendicular. This state approximates moderate flooding of the after sections of the FFG-7. Clearly, there exists variances between the two cases, justifying the inclusion of trim effects on hydrostatic calculations into the Module.

Table 4.1

Flooded Condition: Displacement - 3908 tons
LCG - 226.6 feet aft of FP
VCG - 17.69 feet above Baseline
TCG - 0.0 (centerline)

Parameter	Conventional	Trim Effect
Mean draft (ft)	15.78	15.24
Trim (ft)	7.61	7.64
Forward Draft (ft)	11.52	10.89
Aft Draft (ft)	19.13	18.53
LCB (ft aft of FP)	208.24	226.60
LCF (ft Aft of FP)	228.57	232.23
MTI (ft-tons)	785.78	761.80
TPI (tons)	33.02	32.64
KM (ft)	23.08	22.77
GM (ft) (No free surface)	5.60	5.32

4.2 STATIC STABILITY CURVES

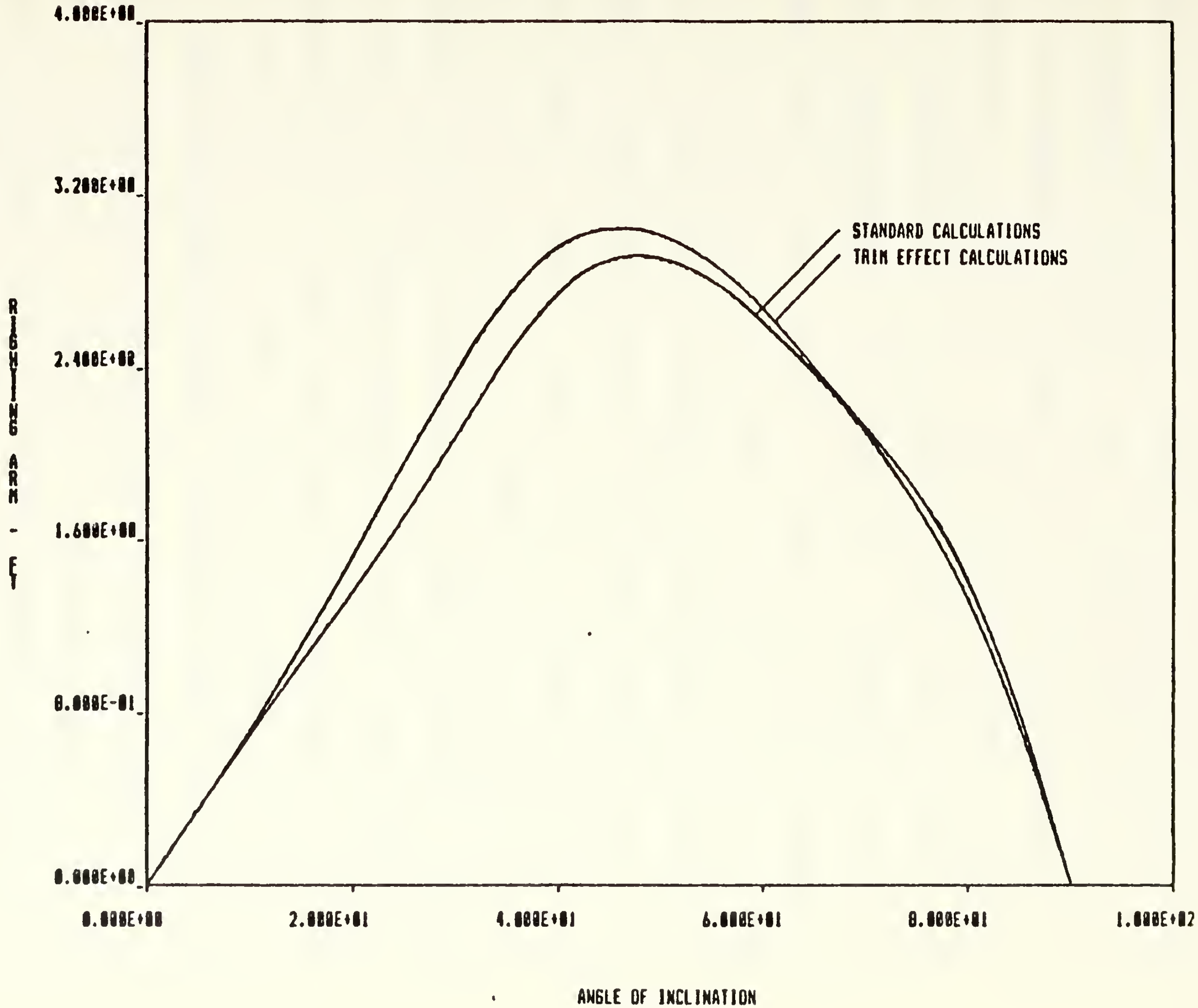
The static stability curve for a given condition of the ship is generated by evaluating the cross curves of stability at the ship's displacement. Also, the trim of the ship must be passed to the subroutine calculating the righting arms. As in the calculation of the hydrostatic parameters, linear interpolation is used to determine the

righting arms between the bounding trim quantities. This interpolation scheme provides excellent results, as the relationship between righting arms and trim is almost linear.

The algorithm utilized to calculate the righting arms for every ten degrees of inclination parallels that used for the hydrostatic calculations. As trim is now a passed argument, the bounding trims are identified and the righting arms for these two trims are calculated. The righting arms for the ship's trim state are then found by interpolation. These values are returned to the subroutine which constructs the curve of static stability. As with the hydrostatic parameters, the righting arms corresponding to the appropriate fifteen foot trim line are used when the trim exceeds this value.

Figure 4.6 presents the static stability curves for the damaged condition described in the previous section for both the conventional, zero trim method and the trim effect method. As with the hydrostatic case, there is a difference in the stability characteristics between the two methods of calculation. Based on an investigation of scenarios, this variance can be numerically significant; and the effect of trim on the stability curves is included in the Module.

Figure 4.6 - Static Stability Curves
Conventional and Trim Effects Calculations



5.0 SENSITIVITY ANALYSIS

The purpose of the sensitivity analysis is to determine the response of the program algorithms to variances of the input data from its actual state. The input data to the Module consists of the liquid load accounting and, in the case of flooding, the level of flooding in the damaged watertight subdivisions. The flooding levels input into the Module do not require a high degree of accuracy if the compartment is in free communication with the sea. The Module performs the flooding calculations iteratively until the interior water level is equal to the waterline at the midpoint of the compartment. Therefore, regardless of the input flooding level, the final flooded state of the damaged compartments will be correctly calculated. Of course, the current flooded condition of the ship will be dependent on the accuracy of this input.

Tanks and compartments flooded from internal sources, such as fire-fighting water and ruptured piping, pose a different problem. The soundings input into the program for these spaces must possess sufficient accuracy in order for the Module to predict the current and final flooded states to a reasonable degree of accuracy. The difficulty in obtaining sufficiently accurate soundings for these spaces is compounded by the differences in the level determination techniques for the two cases. Tanks are sounded by means of sounding tapes; and flooded compartments are sounded by tapping on adjacent bulkheads vertically until the level of flooding is determined by the tonal changes. The later method can only provide the operator with approximate data, however, at the present time, this is the only technique available. Any inaccuracies in the input soundings from this source must be tolerated until

either a reliable system of flooding level indicators is developed, or the accuracy of the method is shown to be sufficient for the Module's purposes. The method and accuracy of tank soundings will be discussed in the following section.

Other variable loads impact the weight condition of the ship from both displacement and position of the center of gravity standpoints. The accounting of stores, provisions, ammunition, and other "solid" variable loads is presently not provided by the Module. However, the accurate determination of these loads can be accomplished. Therefore, these variable loads were not considered to be a potential source of error for the analysis.

Therefore, the inaccuracies inherent to the system arise from two sources, tankage and internally flooded compartments. Unfortunately, the level of accuracy available for the two sources is different, based on the current sounding techniques. Therefore, the assumption was made to consider only those inaccuracies in the initial load accounting of the ship and determine their effects on the final flooded state of the ship. These errors will be far more prevalent; and the errors due to internally flooded compartments may be treated in the same manner as the single compartment effects on stability.

5.1 TANKAGE SOUNDING TECHNIQUES

A brief description of current U. S. Navy sounding practices is helpful in determining the degree of inaccuracy expected from tank soundings. Every tank and void of a ship is fitted with a sounding tube which is labeled to indicate the particular tank it serves. The person

sounding the tank removes the sounding tube cap and runs a weighted tape measure down the tube until it strikes the bottom of the tube. The tape is then withdrawn from the tube and the liquid level is read in the same manner as an oil dipstick for an automobile. The reading, in feet and inches, is converted to gallons by the use of a capacity chart or graph for the given tank. As in the case of an automobile, this is only a single point reading and the attitude of the tank with respect to the horizontal will effect the level reading. As this is a manual method, the technique of the person sounding the tank may also introduce inaccuracies in the reading. In addition, although the labeling of sounding tubes is a requirement, the maintenance of these labels is occasionally difficult; and the possibility exists that the wrong tank may be sounded. Debris in the bottom of the tube will also cause errors.

The attitude of the tank will give rise to the majority of the errors, if proper technique and maintenance is utilized. The position of the sounding tube in the tank is critical in determining the mean level. Very few sounding tubes are placed along the vertical centerline of the tank due to placement considerations of the top ends. Additionally, the attitude of the tank is dependent not only on the trim and list of the ship, but also the dynamic motions of pitch and roll. However, improved accuracy can be achieved through the generation of correction charts which take into account the heel and trim of the ship and the position of the tube in the tank.

Although the possibility of some error is great, interviews with Naval Officers, who have served as Engineering Watch Officers, lead to the conclusion that soundings are usually reasonably accurate. This is

primarily due to the frequency of soundings, once every four hours, allowing those responsible to recognize a sudden large increase or decrease in a tank's reported level as a possible error. The re-sounding of the tank in question will often correct the inaccuracy. Also, as the amounts of fuel, potable water, boiler feed water, and lubricating oil are critically important for destroyer and frigate sized ships, great care is taken in the sounding of tanks. Conservative estimates from a survey of Naval Officers and Chief Petty Officers indicate that an accuracy of plus or minus ten percent per tank is the worst case expected. The reader is cautioned that this is a qualitative estimate based on experience rather than a numerical analysis.

5.2 METHOD OF ANALYSIS

The sensitivity analysis was carried out by imposing damage on the ship for a series of various initial conditions. The ship was allowed to flood to its final equilibrium position and the parameters defining the state of the ship were compared to both its intact condition and a baseline damaged condition. The sequence of the various initial conditions was based on the plus or minus ten percent expected accuracy detailed in the previous section.

5.2.1 IMPOSITION OF DAMAGE

The Damage Control Manual for the FFG-7 indicates that flooding between bulkheads 100 and 212 poses the greatest threat to the residual stability of the ship [12]. This corresponds to the worst case condition for the standard fifteen percent length of damage criterion; and

was chosen as the damage to be inflicted for the purpose of the analysis.

The baseline ship condition for the analysis was chosen to be the minimum operating, or one-third fuel and stores remaining condition. Table 5.1 depicts the loading condition for this case.

Table 5.1 Summary of Loading Condition

Category	Tons	VCG	LCG (-AFT)	TCG (-PORT)	FRSURF
Fresh Water	18.4	8.406	-112.78	-1.437	6.9
Lube Oil	4.4	14.813	-73.57	-18.969	1.2
Fuel Oil	340.5	7.166	58.53	0.005	472.4
JP-5	21.6	10.274	-143.96	2.922	159.8
Misc Tanks	23.2	3.472	52.50	-0.238	54.7
Ballast	129.1	7.954	33.49	0.0	0.0
Flooding	0.0	0.0	0.0	0.0	0.0
Ammunition	50.0	32.870	37.91	0.0	0.0
Aircraft	18.0	32.870	37.91	0.0	0.0
Provisions	22.0	16.910	14.50	0.0	0.0
General Stores	18.0	24.170	31.70	0.0	0.0
Crew	21.0	22.330	50.30	0.0	0.0
Light Ship	2641.0	20.590	-13.79	0.0	0.0
TOTAL	3307.2	18.714	-4.37	-0.015	695.0

After initializing the ship's intact condition, the damage was imposed to the starboard side with a transverse extent to the centerline. The first step was to fill all tanks not already full in the standard minimum operating condition. Table 5.2 presents the affected tanks.

Table 5.2 Tankage Affected by Damage

Tank	Liquid	Initial Status	Full Capacity (Tons)
5-164-3-F	Fuel Oil	Empty	9.47
5-140-1-F	Fuel Oil	Empty	28.93
5-116-1-F	Fuel Oil	Empty	66.86
5-164-0-F	Oily Waste Holding	43%	7.07
5-170-0-F	Waste Oil Retention	40%	13.14
5-132-0-F	Cont. Oil Settling	65%	19.69

Then, the fourth and fifth deck subdivisions were flooded until stabilized or full. These spaces correspond to the APU Machinery Room, Ship's Laundry, and Auxiliary Machinery Room Number One. If these spaces filled completely, the third deck spaces immediately above were flooded, and the final state determined. The third deck subdivisions affected correspond to the two forward Crew's Berthing Areas and the Provisions and Chilled Storerooms. As these spaces did not fill completely at any time, flooding of the second deck was not necessary. The standard assumption of non-watertight decks was used throughout the analysis. In addition, a beam wind of 15 knots was imposed on the ship in the damaged condition.

5.2.2 ANALYSIS CASES

As previously mentioned, an accuracy of plus or minus ten percent of capacity per tank was taken to be the worst case expected. Although it is highly unlikely that every sounding in a given series would exhibit this degree of inaccuracy, the situation could develop, for example, that all tanks forward of the LCG could be read ten percent high and those aft read ten percent low. This corresponds to a change in the

total ship's moment, displacement times LCG, of 22.4 percent. Therefore, a range of plus or minus 25 percent in the ship's intact moment was chosen as the range for the sensitivity study. However, it should be emphasized that the endpoints of this range of conditions are highly unlikely. If the error in a tank sounding may be taken as random, yielding a Gaussian distribution for each tank, the distribution of error for all the tanks would also be Gaussian with a very low probability of extreme error. The most probable situation would be a series of small errors in which some cancel the effects of others.

There are two means by which the total ship's moment may be varied. A weight can be added at a particular location to increase or decrease the moment, or the LCG of the ship can be shifted to produce the same moment variation. It was decided to achieve both cases by varying the input light ship weight or LCG, as appropriate. A third series was run based on both a weight addition and LCG shift to maintain the ship's moment at its intact value. This case was selected to investigate the effects of weight addition at the LCG of the ship. Table 5.3 details the variances in the light ship weight and LCG for the three sequences. Vertical and transverse moments were held constant throughout the run.

Table 5.3 Summary of Parameters Varied for the Sensitivity Analysis Studies

Minimum Operating Condition:	Weight	- 3307.2 tons
	LCG	- 4.37 ft aft of Sta. 10
	Moment	- -14464.3 ft-tons
Actual Light Ship Condition:	Weight	- 2641.0 tons
	LCG	- 13.79 ft aft of Sta. 10

Figures given as "Light ship weight"/"Light ship LCG"

Percentage	Displacement Moment	LCG Moment	Displacement Only
25%	2904.1/-13.79	2641.0/-15.16	2904.1/-12.94
20%	2851.6/-13.79	2641.0/-14.89	2851.6/-13.09
15%	2799.2/-13.79	2641.0/-14.62	2799.2/-13.26
10%	2746.9/-13.79	2641.0/-14.34	2746.9/-13.43
5%	2694.5/-13.79	2641.0/-14.07	2694.5/-13.60
0%	2641.0/-13.79	2641.0/-13.79	2641.0/-13.79
-5%	2589.6/-13.79	2641.0/-13.52	2589.6/-13.98
-10%	2537.1/-13.79	2641.0/-13.25	2537.1/-14.18
-15%	2484.7/-13.79	2641.0/-12.97	2484.7/-14.38
-20%	2432.0/-13.79	2641.0/-12.70	2432.0/-14.60
-25%	2379.6/-13.79	2641.0/-12.43	2379.6/-14.82

5.3 RESULTS OF THE SENSITIVITY ANALYSIS

The following sections summarize the effects of varying the ship's moment by both weight addition and LCG shift methods and the ship's displacement. The parameters chosen for detailed study are those which would be of the most concern to the Damage Control Officer in the event of damage. The selection of these quantities was based on experience and a study of critical hydrostatic and stability parameters detailed in War Damage Reports. The functions selected for detailed study are ship sttitude, GM, amount of flooding water, angle of maximum righting arm, and mean draft. Parameters of secondary importance are also briefly discussed.

Prior to proceeding to the results of the analysis, a review of the three cases is in order. The initial ship's moment is negative, as the LCG is aft of the reference point of midships. An increase in moment, resulting in a more negative moment, is achieved by moving the LCG aft, or increasing the light ship weight at the intact LCG. The displacement only case is produced by adding the weight associated with the corresponding displacement moment percentage to the light ship load and shifting the light ship LCG to maintain the ship's intact LCG at a constant position throughout the analysis.

5.3.1 SHIP ATTITUDE

The trim and heel of the ship, in the damaged condition, are important for several reasons. Obviously, the attitude of the ship, combined with the mean draft, directly determines the minimum freeboard. Therefore, excessive trim and heel will reduce the reserve buoyancy and may even cause premature immersion of the deckedge. Conditions of large heel and trim can also result in the uncovering of seachests located on the ship's side, rendering the equipment serviced by such openings inoperable. For example, the loss of a firepump from this type of action affects both the firefighting and dewatering, by eductor, capabilities of the ship. The attitude of the ship can also impact the operation of the combat system by exceeding the limitations of the launcher, fire control, or radar systems. Consequently, an accurate prediction of the ship's attitude is essential in the determination of the survivability of the ship.

In all three cases, the heel of the ship, caused by off-center weights and beam winds, remained relatively constant at four to five degrees. Although not specifically studied, wind velocities of 50 knots were imposed on the ship; and there was very little deviation of heel for the range of moments. Therefore, the heel of the ship appears to be insensitive to both moment changes and weight additions.

The trim of the ship varies modestly throughout the range of moment and displacement variations. Figure 5.1 depicts the variation of the initial and final trims for the three analysis cases. As can be seen, increasing LCG moments increase the trim by the stern as expected. The variation from the baseline condition is approximately an increase of four inches for the 25 percent increase of moment for the initial and final states. For the 25 percent reduction of moment case, the variation of trim from the baseline value was a decrease of five inches in the intact case and four inches in the damaged case.

For the displacement moment and displacement only cases, the behavior is opposite that of the LCG moment case. For both cases, the addition of weight aft results in a decrease in the stern down trim for both the initial and final states. The trim, for an increase of 25 percent of the displacement moment, decreases the trim by 3.7 inches in the intact condition, and by 9.1 inches for the damaged condition. For the 25 percent reduction case, the trim increases by 3.5 inches and 2 feet 2 inches for the initial and final conditions, respectively. The displacement only case follows the same trends, as shown. Therefore, the addition of weight to the ship not only demonstrates the program's sensitivity to this condition, but also results in a reversal of the expected trends.

Figure 5.1 - Intact and Damaged Trim vs Percentage Change of Moment for the Three Analysis Cases

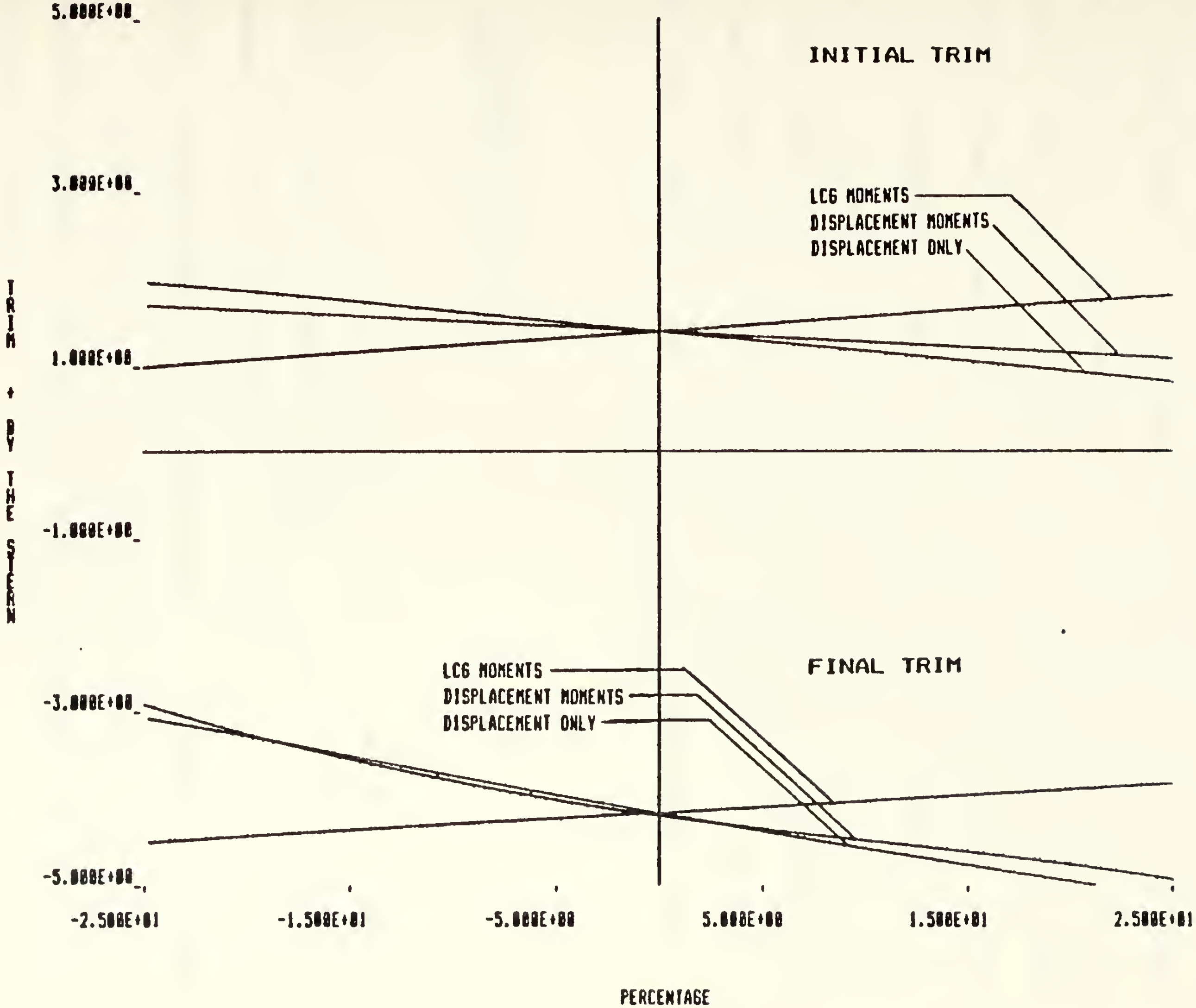


Figure 5.2 explains the apparent inconsistency of weight addition aft resulting in a decrease in trim, for the intact case. The curves for the one and two foot trim lines represent the position of the LCB for the corresponding trim as a function of draft. The line labeled "LCG Moments" is the progression of the ship's LCG as the moment of the ship is varied from 75 to 125 percent of its baseline value. As weight was not added in this case, the draft does not change; and the LCG moves horizontally resulting in a higher trim. However, the line marked "Displacement Moments" demonstrates the right to left motion of the LCG shift and an increase in draft corresponding to the increase in displacement. This line is characterized by a greater slope than the LCB trim lines, producing a decrease in trim for this condition. The "Displacement Only" line is, by definition, vertical and is included as a comparison. Therefore, the behavior of the displacement cases is verified.

5.3.2 METACENTRIC HEIGHT (GM)

Figure 5.3 depicts the behavior of GM for the three analysis cases for the intact and damaged scenarios. As GM is the most commonly used parameter by which the stability of the ship is measured, an understanding of the sensitivity of this parameter to variations in the input data is of critical importance to the operator of the Stability Module. The metacentric heights depicted in figure 5.3 include the adjustment for free surface effects.

The effect of LCG moments, throughout the range of variation, on the GM of the ship is negligible for both the intact and damaged cases.

Figure 5.2 - Moment Progression

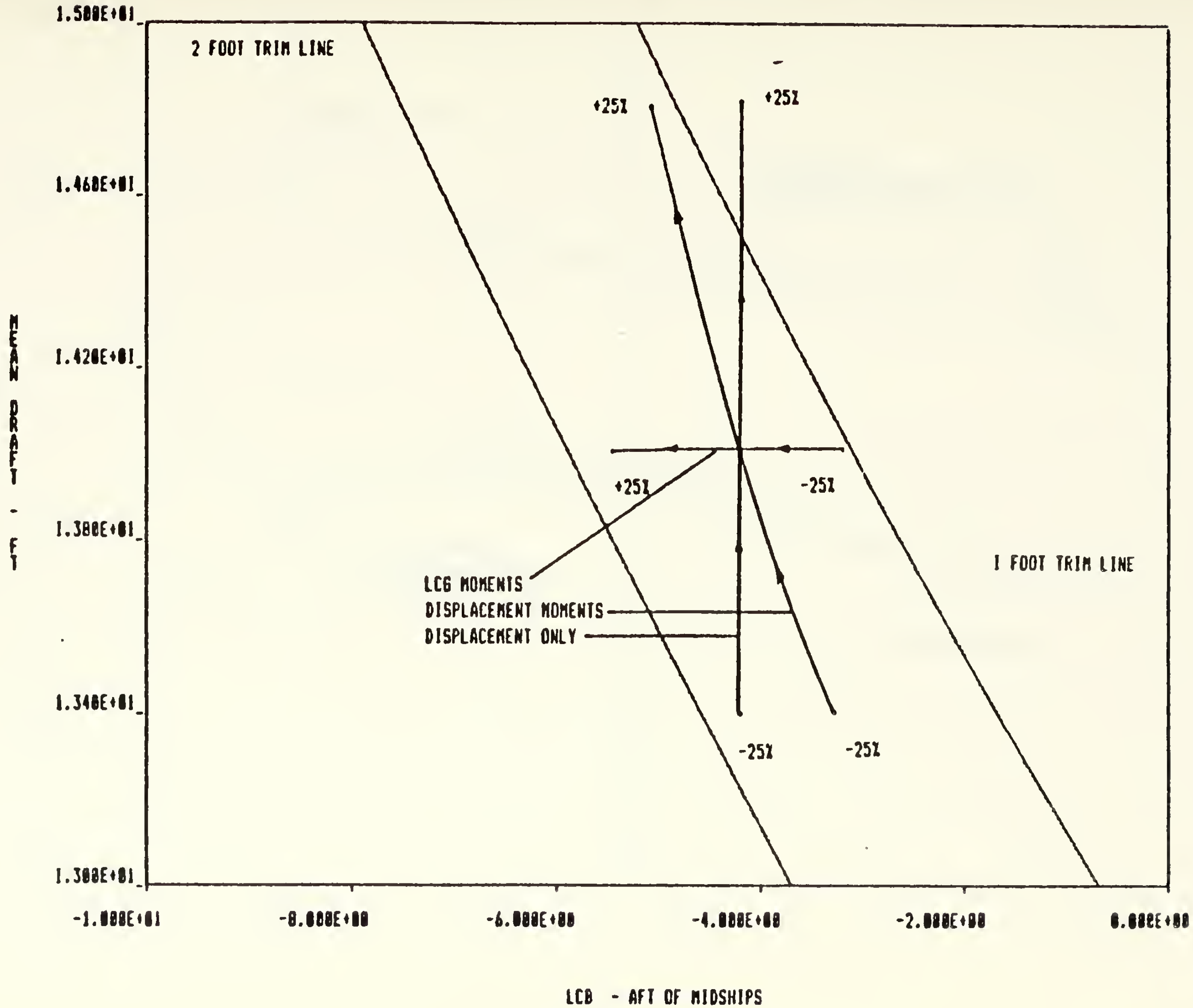
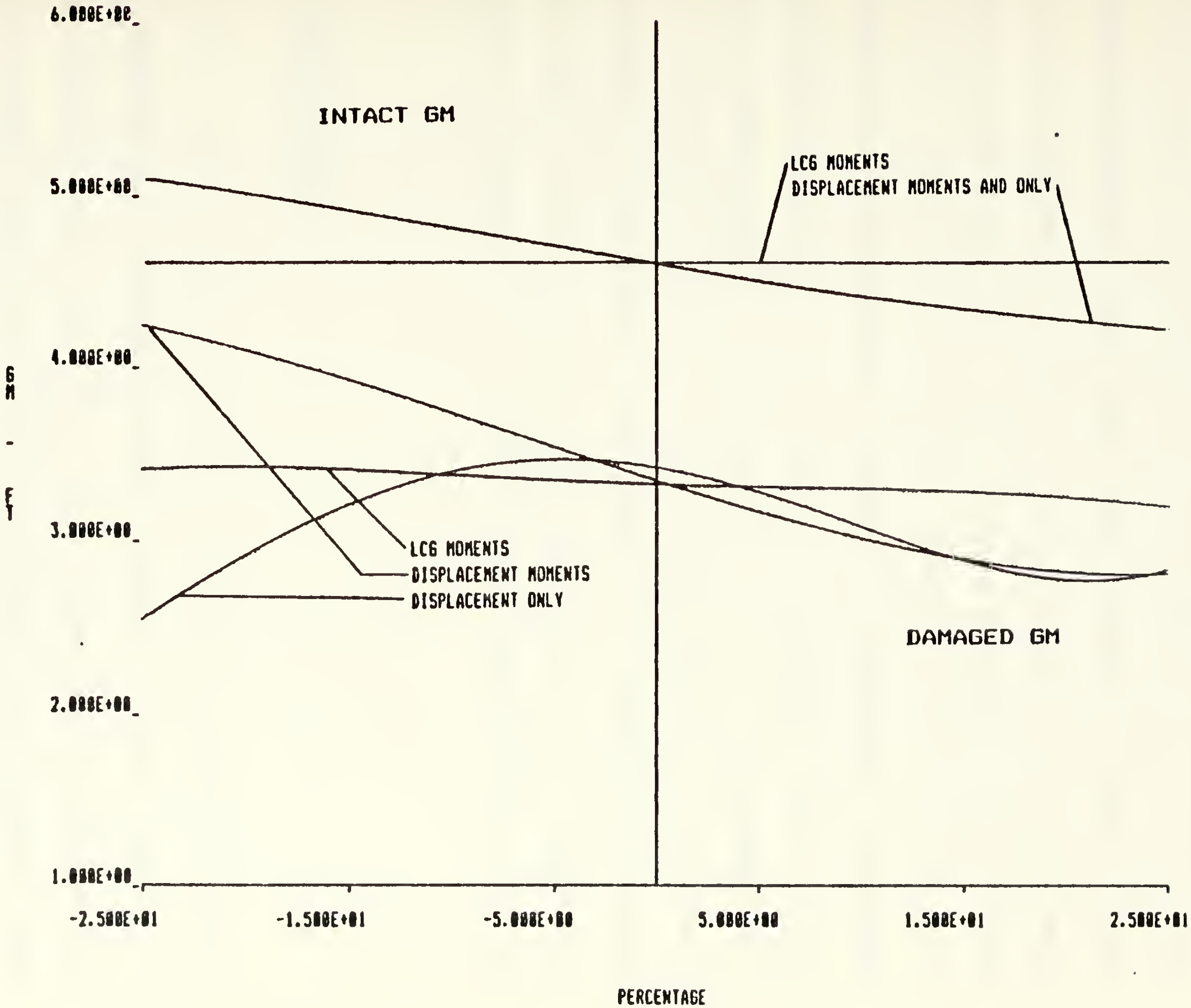


Figure 5.3 – Intact and Damaged GM vs Percentage Change of Moment for the Three Analysis Cases



The insensitivity of GM to the position of the LCG is due to the relative constant trim and displacement of the ship, resulting in only minor variances in KM and the amount of water allowed into the ship.

However, both displacement variation cases demonstrate a variance of plus or minus 0.5 feet of GM for the intact case. The GM decreases with increasing displacement and moment. This is due to the general trend of KM to decrease in this draft range for positive trims. For the damaged case, the behavior of GM for increased moments and displacements is similar to the intact case. The enhanced deviations from the baseline condition are due to free surface effects. Free surface effects also account for the disparity between the displacement moment and displacement only cases in the negative percentage range. Slight variances in the position of the waterline in way of the damage causes the third deck spaces to flood for the displacement only case prior to the displacement moment case. The results in an increase in the free surface effect in this range of moment variation for the displacement only series, resulting in a significantly reduced GM due to free surface.

5.3.3 FLOODING WATER

The amount of water admitted into the ship as a result of flooding is important as it defines the time required to restore the ship to its best possible state, based on a fixed dewatering capacity; affects the free surface effect on stability parameters; can produce severe bending moments on the hull structure; and determines the damaged draft,

heel, and trim. The ability of the Module to accurately predict the final amount of flooding water is crucial to all other analyses it performs.

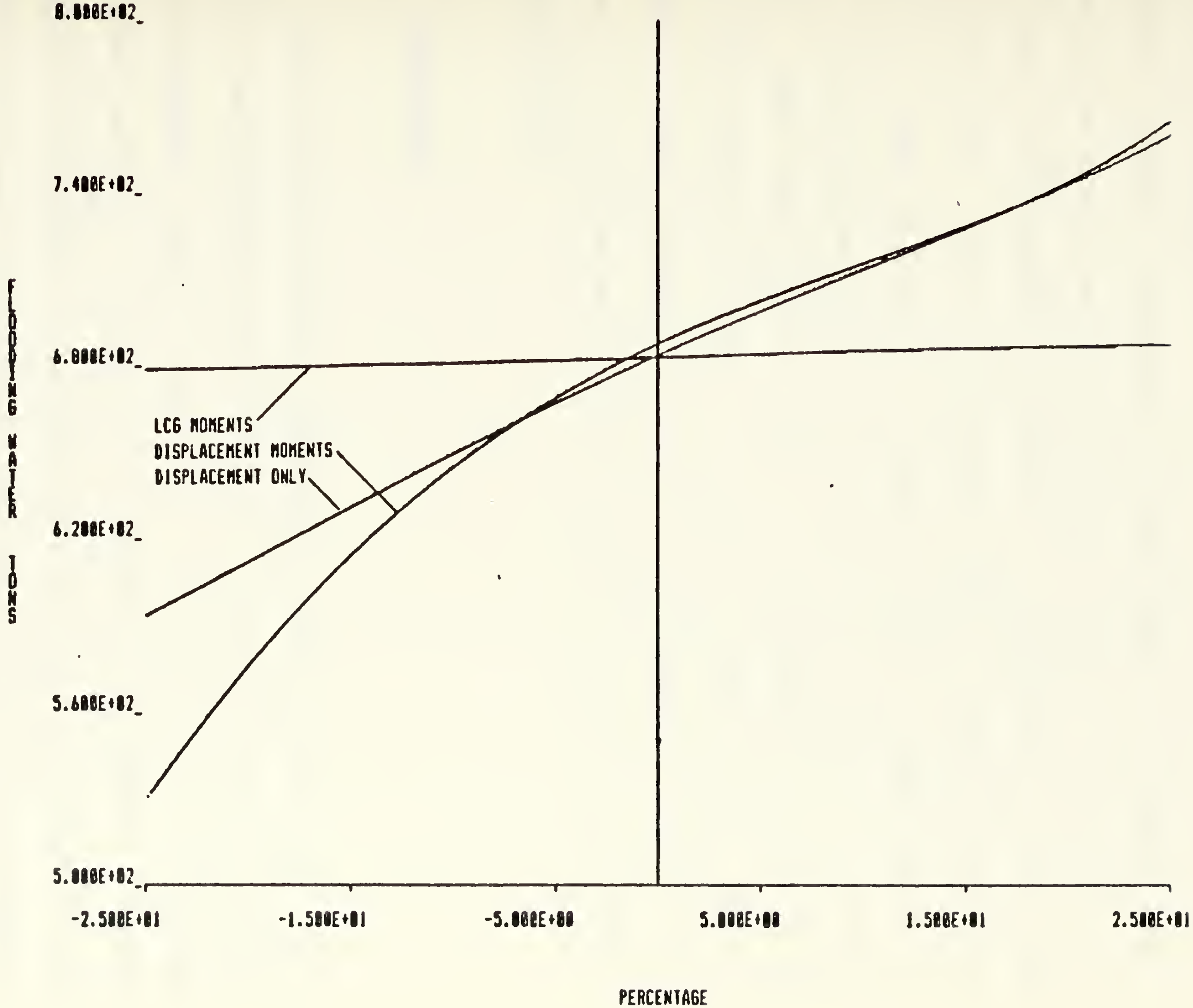
As shown in figure 5.4, LCG moment variations do not effect the degree or extent of flooding. As previously mentioned, the variance of trim and displacement is relatively small for this case. This results in an insensitivity of the amount of flooding water to errors which manifest themselves as LCG shifts only.

However, displacement and displacement moment variances result in varying amounts of flooding water allowed into the ship. Due to the increase of the bow down trim for positive percentages, more water is allowed to enter the ship in this range. Due to the iterative nature of the algorithms utilized by the program, this added weight forward increases the bow trim further to allow even more water to enter the ship. Therefore, the effect of an inaccurate load determination prior to damage is "magnified." This results in an over estimation of the weight of the flooding water taken on by the ship by 120 tons for the 125 percent of intact displacement moment case. The opposite analysis applies for a reduction in the displacement moments. As before, the effect of the third deck becoming awash for the displacement only case at lower percentages than the displacement moment case is evident.

5.3.4 ANGLE OF MAXIMUM RIGHTING ARM

The angle at which the maximum righting arm occurs is an indication of the range of roll the ship may safely experience. Roll motions past this angle result in a steadily decreasing righting arm and dynamic

Figure 5.4 - Amount of Flooding Water Admitted vs Percentage Change of Moment for the Three Analysis Cases



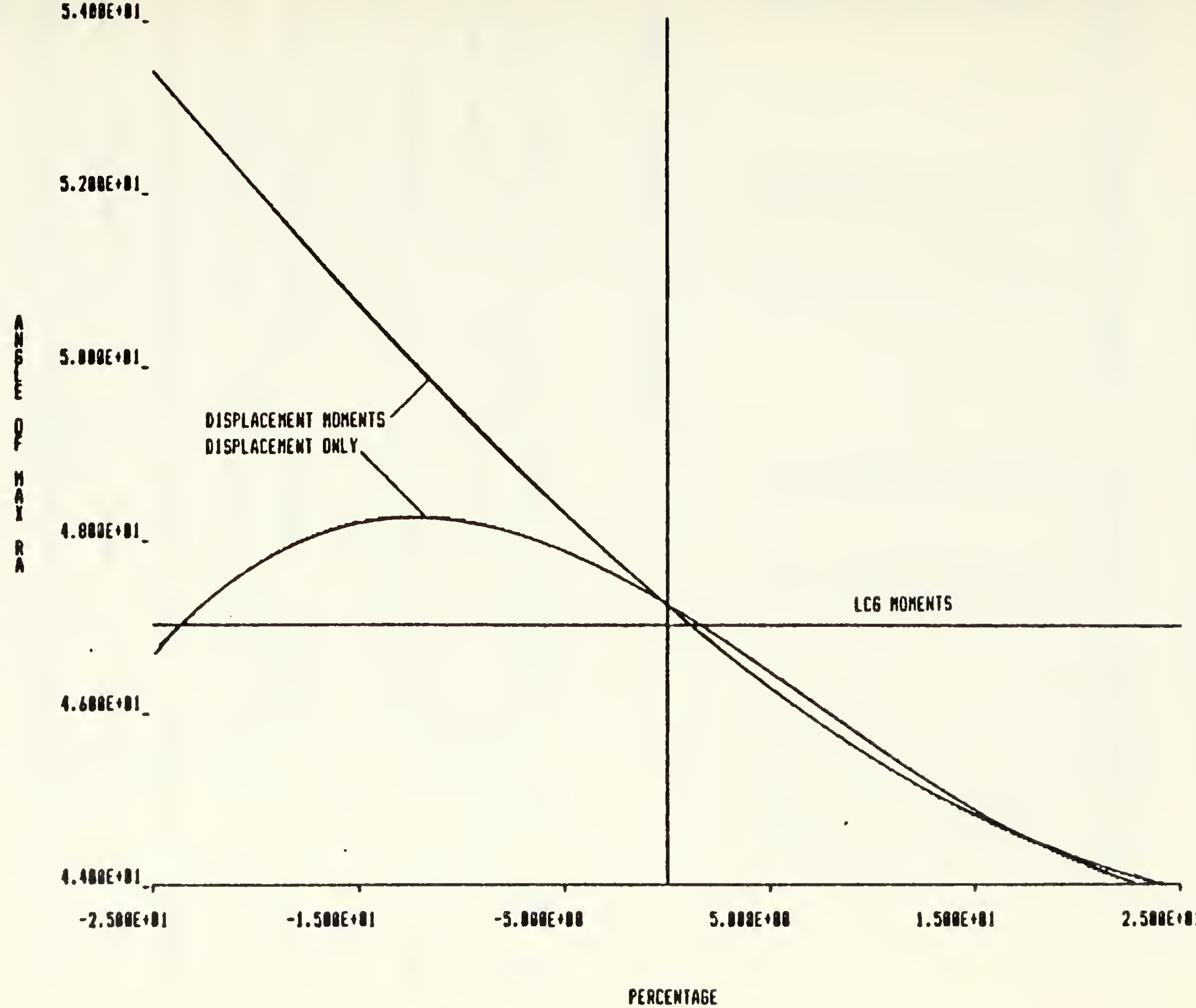
righting force, equivalent to the area under the static stability curve. Although this is not to imply that the ship is unstable past this point, this angle is a benchmark, used by the crew, to determine a safe range of roll in the damaged condition. Therefore, an accurate determination of this angle is required.

Figure 5.5 depicts the variation of the angle of the maximum righting arm for the three cases for the damaged condition. As with the previous cases, the LCG moment case exhibits an insensitivity of this angle to the LCG shift. The two displacement modes do, however, show some variation. Figure 5.5 depicts a general trend to underestimate this angle for increasing percentages and overestimate the angle for reduced moments. Again the deviation of the two displacement cases due to the free surface effect is evident. It should be noted that the range of variation of this parameter is negative two degrees to positive six degrees for the extreme moment variations, with respect to the baseline damaged condition.

5.3.5 MEAN DRAFT

The mean draft dictates the reserve buoyancy of the ship. Table 5.4 lists the variations of mean draft for the three cases as a function of the percentage change of the intact ship's moment for the damaged case. The behavior of the mean draft throughout the range of variation is similar to the amount of flooding water admitted. As before, the LCG moments do not cause a significant change in the draft over the range of interest. The displacement cases closely approximate one another; and

Figure 5.5 – Angle of Maximum Righting Arm vs Percentage Change of Moment for the Three Analysis Cases



demonstrate a trend of increasing draft for increasing moment. This is obviously due to the weight addition common to both the displacement analyses.

Table 5.4 Mean Draft Variations

Percentage	Displacement Moments	LCG Moments	Displacement Only
-25%	13' 4.1"	14' 1.1"	13' 4.0"
-20%	13' 5.9"	14' 1.1"	13' 5.8"
-15%	13' 7.6"	14' 1.0"	13' 7.6"
-10%	13' 9.4"	14' 1.0"	13' 9.0"
-5%	13' 11.2"	14' 0.9"	13' 11.1"
0%	14' 0.9"	14' 0.9"	14' 0.9"
+5%	14' 2.7"	14' 0.8"	14' 2.7"
+10%	14' 4.4"	14' 0.8"	14' 4.5"
+15%	14' 6.2"	14' 0.7"	14' 6.3"
+20%	14' 7.9"	14' 0.7"	14' 8.1"
+25%	14' 9.6"	14' 0.6"	14' 9.9"

5.3.6 OTHER HYDROSTATIC PARAMETERS

The behavior of the hydrostatic parameters MTI, TPI, and LCF follow the same trends described in Chapter 2. the variation of the trim and displacement of the ship appears to exert the controlling influence over these parameters. LCG moments do not appreciably affect the values of these parameters throughout the range of the analysis. For the displacement cases, MTI and TPI increase in value slightly as the moment percentages increase. The LCF remains relatively constant, varying less than two feet for these cases. In conclusion, the effect of inaccurate input data is negligible on the parameters of MTI, TPI, and LCF.

5.4 CONCLUSIONS

Based on the previous analysis, the Module's accuracy is affected by displacement variations rather than by movement of the LCG. In all cases, the LCG moments produced only minor deviations from the baseline ship conditions. The addition of weight to the ship, on the other hand, did result in noticeable changes of the parameters investigated. However, these variations were most pronounced at the extreme points of the moment variation range. As previously mentioned, the probability of this degree of inaccuracy is highly unlikely. Except after refueling, the majority of the tank soundings will not change from reading to reading. And those readings that do change, fuel service tanks, water tanks being filled, and feed water tanks supplying the boilers, are closely monitored, as inaccurate level determinations can result in more immediate problems than a slight inconsistency in the draft readings. It is the author's judgement that a range of plus or minus 5 percent constitutes the range in which the majority of the errors will lie. Table 5.5 details the percent deviation from the baseline condition of the key parameters fro this range for the three cases.

Table 5.5 +/- 5% Variations of Key Parameters

Parameter	Displacement Moment		LCG Moment		Displacement Only	
	+5%	-5%	+5%	-5%	+5%	-5%
Initial Trim	-4%	+4%	+7%	-5%	-8%	+8%
Final Trim	-4%	+4%	+2%	-2%	-5%	+5%
Initial GM	-2%	+2%	0%	0%	-2%	+2%
Final GM	-3%	+6%	0%	0%	-3%	+6%
Flooded Water	+2%	-2%	<+1%	<-1%	+2%	-2%
Angle of Max RA	-2%	+2%	0%	0%	-2%	+2%
Mean Draft	+1%	-1%	<+1%	0%	+1%	-1%

As none of the above variances is greater than ten percent, the Module is relatively insensitive to errors of this order of magnitude. As in any analysis of this sort, the determination of "Good Enough" is always a matter open to interpretation. The above errors are all in the range of one degree, one inch, one tenth of a foot, or ten gallons, as appropriate. This level of accuracy is certainly sufficient, or "Good Enough," to use the Module with confidence to predict the effects of damage.

6.0 CONCLUSIONS

As previously stated, the purpose of this thesis is the investigation of the effect of trim on the hydrostatic and stability parameters which define the state of the ship. The inclusion of these effects into the Stability Module is based on the improvement of accuracy of the program's output gained from these effects. In addition, a sensitivity analysis of the Module was undertaken to analyze the effects of input data inaccuracies on the output parameters considered key in determining the stability characteristics of the ship.

Several other facets of the Stability Module were investigated that are not directly associated with the hydrostatic and stability calculation techniques. The data base defining the capacity curves for all watertight subdivisions was extended to include all tankage and all watertight compartments below the second deck. An investigation of the information required to make the decisions necessary to efficiently combat flooding led to the extension of the Damage Control Logic implemented by LT Sander in the initial version of the program [8]. This investigation included the potential utilization of the program and recommendations on modifications of the system's output format. These items, and other areas of suggested further development, are discussed Chapter 7.

6.1 HYDROSTATICS AND STABILITY

A key requirement of the Stability Module is the accurate prediction of the ship's final stability state after damage. To achieve this

accuracy, the program algorithms which calculate the hydrostatic and stability parameters should not include assumptions which limit the Module's range of usefulness. This is particularly important for the damaged case, as the trim and heel of the ship can become very significant. It is also for these extreme attitudes that the accuracy of the algorithms is the most important, as the stability of the ship under these conditions is the most critical.

The standard method of stability determination assumes that all hydrostatic and stability parameters do not vary significantly with trim. As a result, these quantities are determined based on a ship condition of zero trim, and utilized for all calculations. However, as detailed in Chapter 2, the hydrostatic parameters which define the ship's draft, trim, and resistance to change of these quantities (MTI and TPI), do vary appreciably with trim. Therefore, a more accurate method of determining the hydrostatic state of the ship is available. Also, the hydrostatic function of KM varies with trim, directly affecting the GM of the ship.

The precise definition of the damaged waterline is crucial to the accurate prediction of the ship's damaged condition. As the program iterates until a static equilibrium condition exists, any error in the draft in way of the damage will result in an inaccurate determination of the flooding water allowed into the ship. This effect carries through the series of calculations and enhances the original error. An excellent example of this, though in a different context, is the effect of displacement errors on the amount of flooding water allowed in the ship in the sensitivity analysis. Errors in the amount of water entering the

ship impact virtually every aspect of the stability analysis. The center of gravity will be affected in all three dimensions resulting in trim, heel, and GM errors. The inaccuracy of the total displacement of the ship affects the mean draft calculations and righting arm curve selection. It is important to remember that the mean draft is the independent variable for all other hydrostatic parameters. Therefore, the inclusion of trim effects on the hydrostatic parameters required for stability calculations is highly recommended.

The effect of pocketing on the free surface effect correction was also investigated. Factors for the Moment of Transference were derived and compared to the standard calculations. It was determined that the inclusion of these factors would not significantly improve the accuracy of the module. This was based on the criteria stated in Section 2.7. However, for ship types characterized by large free surfaces in the intact condition this effect should be included. In order to accomplish this, a significant revision of the appropriate load accounting sections of the Module would be required.

The cross curves of stability were also shown to be trim dependent. These curves are used by the Module to construct the curve of static stability for the ship's displacement. This curve is extremely important as it defines many of the stability parameters considered by the Damage Control Officer in judging the condition of the ship. Therefore, an accurate determination of the righting arm curve is essential to the efficient execution of any damage control measures.

In the damaged condition, the maximum righting arm and angle of maximum righting arm are used as criteria to gauge the stability characteristics of the ship in the same manner as GM. These quantities were

shown to vary with trim in Chapter 3. However, the most significant trim effect on the stability curve is the variation in the area enclosed by the curve. This area is a measure of the energy the ship possesses to withstand dynamic motions. The comparison of various portions of this area is the basis for the stability analysis of the program. As demonstrated in Chapter 3, the change in this area for various trims, at a given displacement, is most significant at light and very heavy weight conditions. Therefore, for the Module to accurately assess the stability of the ship for all loading and damaged conditions, this dependence of the stability curves on trim must be included in the program.

6.2 SENSITIVITY ANALYSIS

The sensitivity analysis, detailed in Chapter 5, was performed in order to determine the degree of accuracy required of the input parameters to insure the proper calculation of the stability characteristics of the ship. An accuracy of plus or minus ten percent per tank was chosen as the limiting worst case. This selection was based on the results of interviews of Naval Officers with shipboard engineering experience. This level of accuracy led to the selection of a variation of the ship's intact moment of 75 to 125 percent. The moment change was accomplished by two methods, LCG shifts and light ship weight adjustments. A displacement only case was also run to attempt to separate the effects of changes in displacement at the LCG of the ship from those resulting from a moment change. Severe damage was imposed on the ship; and the Module determined the final flooded state of the ship. The

hydrostatic and stability parameters deemed crucial to the damage control decision-making process were investigated for both the intact and damaged conditions. This investigation entailed the determination of any deviations of the key parameters from the baseline condition.

Errors in the load accounting of the ship which produce shifts of the LCG and little change in the displacement of the ship do not result in appreciable deviations from the baseline case. This is true for both the intact and damaged cases. This is due to the insensitivity of the trim of the ship to minor errors in the calculation of the LCG. Given a relatively constant trim and displacement as an initial condition, the amount of flooding water is essentially constant throughout the range of moments for the damaged case. Consequently, the parameters defining the state the ship experience only slight deviations from the baseline conditions. Therefore, for the entire range of moment variation, the algorithms of the Module are insensitive to errors resulting in a shift of the LCG.

However, errors resulting in a change of displacement do affect the final state of the ship. In fact, the variances of the parameters can be quite significant at the extreme points of the moment variance. A comparison of the displacement moment and displacement only cases reveals that the driving factor of the deviations is the change in displacement rather than the change in moment.

The probability of an error resulting in the extreme end points of the displacement analysis is extremely low. The five percent change in the displacement only case corresponds to an error of 50 tons. This constitutes a nine percent increase in the total liquid load for the

minimum operating condition, only slightly below the worst case condition of ten percent. Therefore, the actual bounds of the error in the displacement case is approximately plus or minus five percent, with the more probable cases being in the one to two percent range. Although displacement errors cause deviations from the baseline quantities at the five percent points, these changes are always less than ten percent of the baseline values for both the intact and damaged cases. Although accuracy is highly desirable, this desire must be tempered with the requirements of the problem. In the aforementioned range, the damage control recommendations were exactly the same as the baseline case. Therefore, the sensitivity of the Module to errors in the input data is not such that data of the worst expected accuracy would invalidate the program's output.

6.3 GENERAL COMMENTS

Based on the preceding results, an investigation of the trim effects on stability and hydrostatics is in order prior to the implementation of the Stability Module on a ship type other than the FFG-7. The investigation would require a minimum effort as the program 'SHCP' is resident at the Naval Sea Systems Command (NAVSEA).

The inclusion of the trim effects does not noticeably increase the execution time of the program. Therefore, accuracy is not gained at the expense of immediate output.

As a method of comparison, Appendix F contains a sample run from LT Sander's thesis and a run utilizing the trim effects method for the same initial loading and flooding. As may be seen, the results of these two

runs compare favorably, with only the variations predicted from the inclusion of trim effects. The physical presentation of the Module has not been changed during this thesis.

6.4 SUMMARY OF CONCLUSIONS

In conclusion, the effects of trim on the hydrostatic and stability parameters which define the state of the ship were found to vary with trim. This dependence was deemed to cause significant variances in these parameters for various trims over the standard method of zero trim calculations and these effects were installed in the Module on this basis. Due to the size and shape of the tankage on the FFG-7, the effects of pocketing on the free surface correction to GM was not included in the program.. Lastly, the sensitivity analysis of the program revealed that, for an assumed accuracy of tank soundings, the Module's algorithms are insensitive to such errors, providing reasonably accurate parameter values and identical recommendations.

7.0 RECOMMENDATIONS

The purpose of this chapter is to detail areas of study which should be investigated prior to the installation of the Stability Module onboard Naval vessels. LT Sander, in his thesis [8], addresses several pertinent areas of study to which the reader is directed for further information. In some cases, the areas of further study detailed in this chapter are the same as in LT Sander's investigation. This is to highlight these issues which the author felt key to the successful implementation of the system.

7.1 RECOMMENDATIONS FOR THE MODULE'S ALGORITHMS

There are several sources of inaccuracies remaining in the program. Although the assumptions which led to these approximations are valid, the Module is capable of processing the data in a more accurate manner. Also during the development of the Module, several key issues of the damage control decision-making process have not been addressed. These areas require investigation for possible future implementation into the Module.

At the present time, the Module is not capable of varying the type of liquid in a specified tank. For example, only the physical constants associated with fuel oil are used for fuel oil tanks. Two conditions dictate the need for a variable liquid selection. The FFG-7 incorporates the use of ballasting fuel tanks with salt water to maintain stability. This requires that both seawater and fuel oil constants are available for these tanks. Secondly, tanks in way of damage are assumed

to flood with their respective fluids, not seawater. This affects the total displacement of the ship and the off-center weight adjustment to the stability curve. Therefore, a minimum requirement is that the Module should be able to fill all tanks with salt water as well as their respective fluids.

The amount of heel caused by off-center flooding is presently calculated by setting the ratio of the off-center weight moment to ship heeling moment equal to the ratio of the off-center weight heel effect to ship heel. This proportional method is reasonably accurate for small angles in the linear range of the righting arm curve. However, to provide accurate results for the large angles of heel expected from severe damage, a better method is required. It is suggested that an individual righting arm curve analysis is performed for each off-center weight. This method, or one of similar accuracy, should be investigated as single compartment effects are key to the implementation of the Damage Control Logic.

For pocketing effects to be included in the program, the moment of inertia of each tank must be carried individually through the program until the heel angle is determined. This requirement arises from the dependence of the Moment of Transference Factor on the depth to breadth ratio of the tank. In the module's present form, the moments of inertia are summed together prior to this calculation.

Compartments above the damage control deck should be included in the data base. Besides completing the data base, this will allow testing of the program's sensitivity to variations in the amounts of high flooding water from internal sources.

The subject of hull-girder strength has not yet been investigated. However, war damage reports indicate many cases where severe flooding resulted in structural damage to the ship's strength carrying members. Although the loss of section modulus as a result of damage is highly dependent on the method of inflicting that damage, a statistical study in this area may shed light on this problem. The associated problem of bending moment calculation is addressed in any of a number of load computers in civil use. This area should be investigated for possible inclusion in the Module.

The identification of flooding boundaries is highly recommended for inclusion in the Module. This capability would enhance the ability of the program to aid the damage control organization in efficiently countering the flooding threat. The time spent in establishing these boundaries is critical to the survival of the ship. As the Module can immediately supply this information, critical time is saved over that required for the manual methods currently in practice.

Another area of damage control logic presenting a similar problem as the identification of flooding boundaries, is the determination of critical ship's systems threatened by flooding. Again, the module is capable of providing the operator immediately with a list of those combat, propulsion, and electrical systems in way of the damage. This information is an invaluable input when determining the order of restoration, as the operation of one system may take priority over another depending on the tactical situation. Therefore, an investigation of the requirements the inclusion of this feature places on the system should be studied; and, if feasible from program size and execution time standpoints, included in the Module.

The effect of seawater in free-communication with the sea on the metacentric height is also recommended for further study and possible inclusion in the Module. At present, this effect is not accounted for by either iterative techniques or direct calculations. An investigation of this area by the author indicates that an iterative technique, such as used in the calculation of the amount of flooding water, would be preferable. The use of iteration would delete the need for the additional data base input required by the conventional free-communication correction.

7.2 RECOMMENDATIONS CONCERNING THE SENSITIVITY ANALYSIS

Further investigation of several areas of the sensitivity analysis is suggested. Several assumptions were made during the analysis which need to be verified by further work. The following points should be addressed:

- The expected accuracy used as a basis for the analysis should be refined by a numerical study of tank soundings. A formal statistical approach to the determination of tank sounding accuracy may result in a better selection of the limiting cases for the analysis.
- Damage should be imposed to the ship in other locations to ensure that the same trends hold for all possible cases of damage. It is not clear if the ship displays the same degree of sensitivity to input variations for all cases.

- As previously mentioned, the sensitivity of the program to high flooding should be examined. As this type of damage will result in more severe degradation of the stability parameters than the case chosen.

7.3 RECOMMENDATIONS FOR INPUT/OUTPUT FORMAT

A prime consideration in the development of any information system is the manner by which the input is entered and the output is displayed. This form should be such that the user is not inundated with data not required for the decision-making process at hand, or in a manner which does not efficiently present the information. In times of high stress, such as a ship in a damaged condition, this is especially important. This section recommends an alternate format for the Module during the critical phases of the damage control problems.

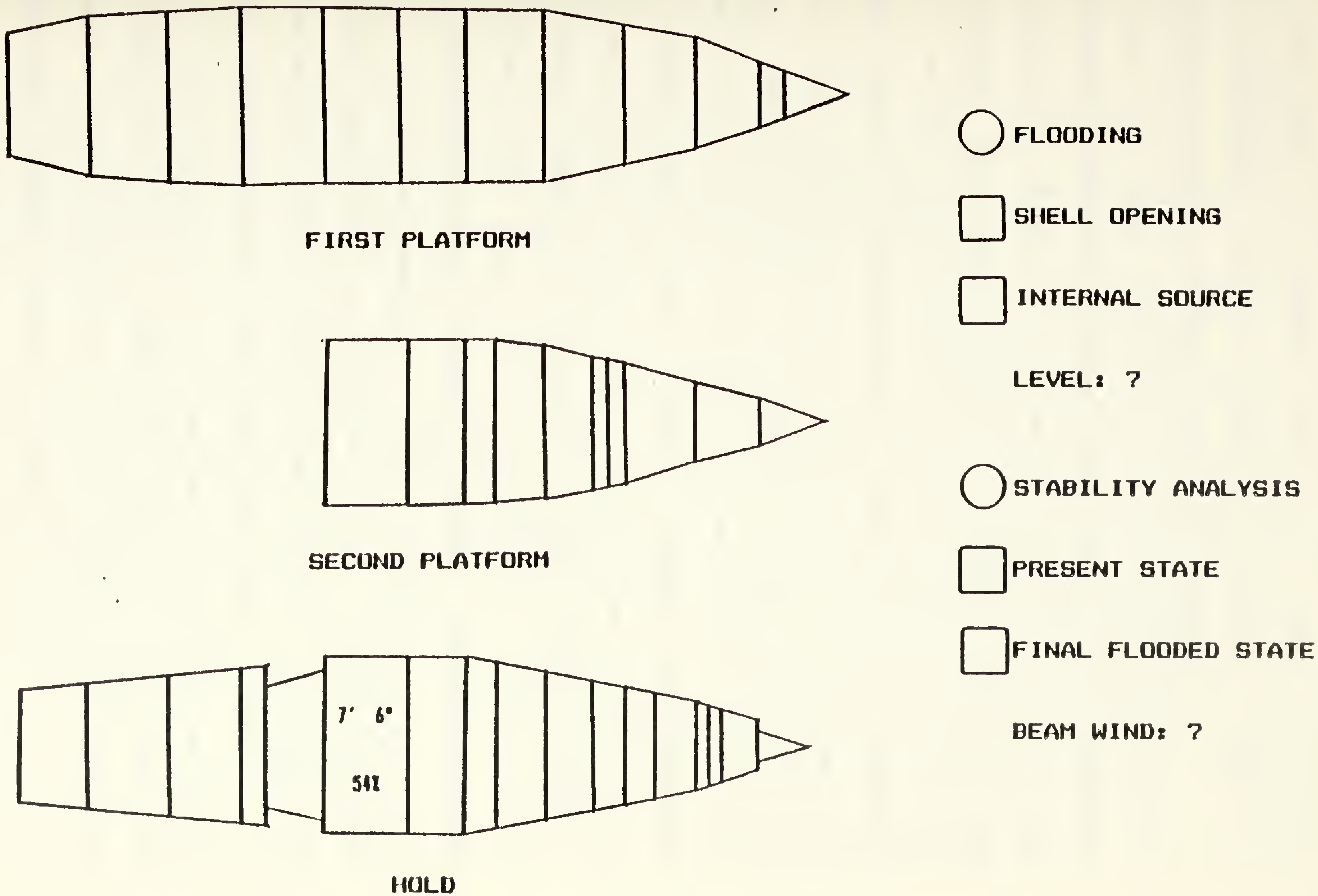
The format presently used by the Module consists of an interaction between the operator and the program via the keyboard. The output is a series of listing detailing the parameters relating to hydrostatics, stability, or damage control recommendations. For daily load accounting and follow-up damage control actions, where time is not a critical factor, this method of interaction is sufficient. However, for time critical situations, this method has the disadvantages of time-consuming typing and output which cannot be quickly evaluated. Figures 7.1 through 7.3 depict an alternate means of input and output formatting which minimizes typing input from the keyboard and graphically presents the required data. It is felt that a graphic representation of the output data would allow the operator to interpret the information with

more ease than comprehending a list of parameters. The output parameters for this method are presented in alpha-numeric lists only when necessary.

The key to this formatting system is the ability to control the functioning of the Module at the screen by means of light-pen or "touch screen" techniques. As these techniques are in common use in the personal computer industry, the technological aspects associated with this system are not considered to be a problem. Therefore, the procurement of the hardware becomes simply a matter of meeting the required specifications.

It is envisioned that upon the infliction of damage to the ship the program would be instructed to enter a "Damage Control Mode." Prior to entering this mode the liquid loading of the ship would be updated, if necessary. Figure 7.1 represents the first screen of this mode to be viewed by the operator. The primary feature of this screen is the deck plans as they would appear on the Damage Control Plates. This figure represents the lower three decks; the upper decks could be presented by selecting another screen or by scrolling. The operator would, by light-pen or touch, select flooding and the source. Flooding level would be input by touching the appropriate watertight subdivision and typing the reported sounding. This level and the amount full in percent would appear in the selected subdivision. In this mode, all liquid parameters would be assumed to be those of seawater. From this point, further flooding could be imposed or a stability analysis of the present or final flooded state entered. Prior to entering the stability analysis section, the beam wind would be input from the keyboard. This parameter and the flooding levels would be the only keyboard entries

Figure 7.1 Flooding Determination - Graphic Method



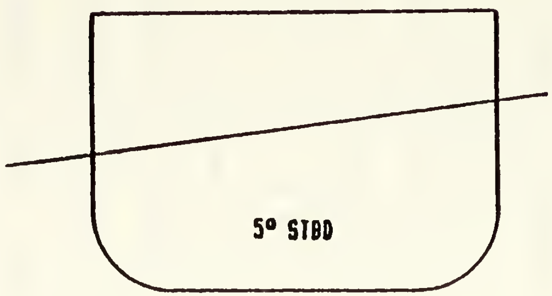
during this phase of the damage control effort. The verification of damage is performed by simply reviewing the deck plans to ensure all appropriate compartments and tanks show signs of flooding.

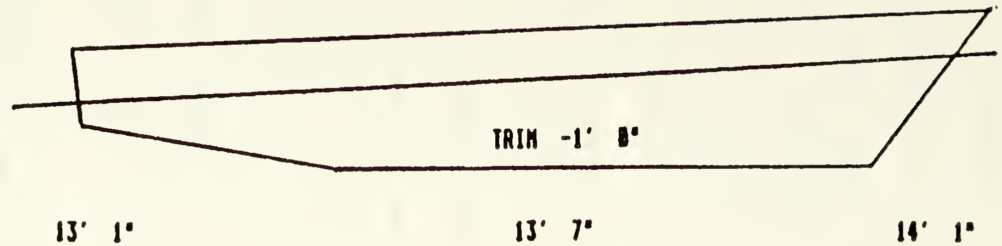
Figure 7.2 presents the stability analysis portion of the graphic output method. Simplified midships section and shear plan representations provide the operator with an immediate view of the ship's waterline position. Heel, trim, and drafts are displayed directly on these views to reinforce the information conveyed. Parameters such as displacement, amount of flooding water, MTI, TPI, and LCF are presented in a short listing. The curve of static stability is also displayed with a listing of the value of GM. The presentation of the righting arm curve was chosen for its ability to display all the critical stability parameters in one concise, easy to interpret diagram. The righting arm curve also allows the Damage Control officer to see the shape of the curve, yielding insight into the amount of dynamic stability available.

Options on this diplay are the selection of a hard copy of the screen, imposition of further flooding, corrective action investigation, or entry into the recommendations section. The hard copy option would be a simple screen dump to an installed printer. A buffer requirement would be imposed so that execution of the program is not delayed. The further flooding option would send the operator back to figure 7.1. The corrective action selection would also send the user back to the previous screen, but with the "What If?" flag set. In this mode, the operator can view the effects of proposed actions on the stability of the ship without changing the actual loading of the ship.

Figure 7.2 Stability Analysis - Graphic Method

STATE: FINAL





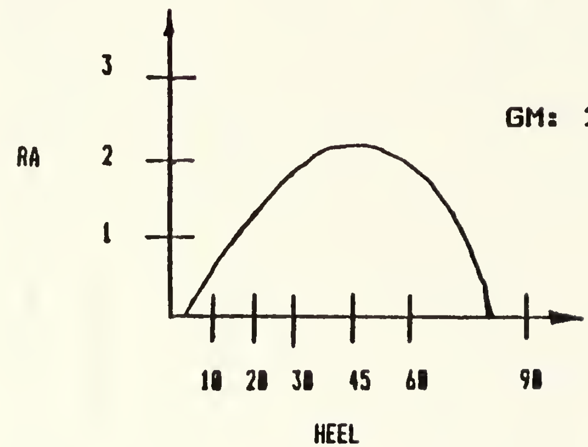
DISPLACEMENT: 4120 TONS

FLOODING WATER: 666 TONS

MTI: 761 FT-TONS

TPI: 31 TONS

LCF: 237' AFT OF FP



☐ HARD COPY

☐ FURTHER FLOODING

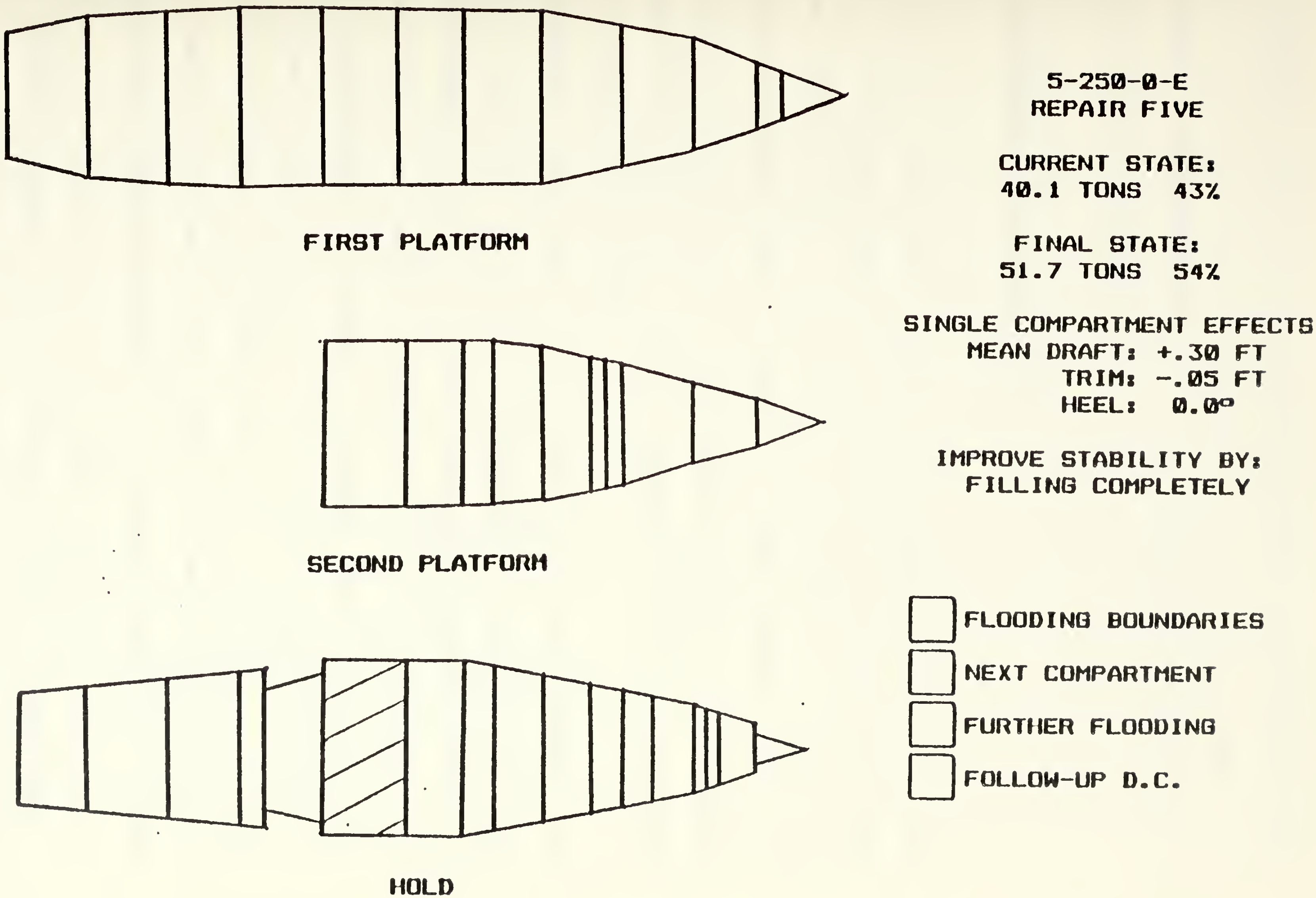
☐ CORRECTIVE ACTION (WHAT IF)

☐ D.C. RECOMMENDATIONS

Figure 7.3 represents an alternative to the immediate action damage control recommendation section of the Module. By touching a flooded compartment, which may be high-lighted in some manner, the displayed listing would be generated. This listing would detail the repair locker responsible for this space, current and final states, single compartment effects, and immediate action recommendations. It is felt that an automatic hard copy of these recommendations be supplied. By presenting the recommendations one space at a time, the Damage Control Officer can investigate only those subdivisions he wishes to compare, rather than a listing of all damaged compartments. From this point, the operator may choose to obtain a listing of the flooding boundaries associated with the selected flooding, investigate the effects of another compartment, impose further flooding if necessary, or exit the damage control mode to the follow-up action recommendations as presently performed by the Module.

The preceding method would allow the Damage Control Officer to efficiently manage the damage control effort with the necessary information in a form which would not saturate his ability to comprehend the data. Utilization of various shading or color schemes could distinguish immediately between different sources of flooding and proposed actions. Dewatering efforts could be checked by selecting flooding from an internal source and reducing the appropriate water level to zero. Transient condition effects on stability could also be checked in this manner. A possible extension to this system could be the installation of flooding sensors throughout the ship and programming the Module to display unreported flooding directly on the deck layouts.

Figure 7.3 Immediate Action D.C. Recommendations - Graphic Method



Therefore, this method is inherently flexible for further capabilities as well as providing a more efficient link between the operator and the Module. The further investigation and development of this type of format is highly encouraged.

7.4 RECOMMENDATION FOR PROGRAM USAGE

The utilization of the Stability Module onboard ships of the FFG-7 class will certainly improve the survivability of the ship with respect to the flooding hazard. In addition, the ability of the Module to accurately and expeditiously determine the final flooded state of the ship may, in extreme cases, aid the Commanding Officer in his decision to abandon the ship or not. However, the Module's greatest contribution may be in the area of training.

Stability calculations are long and tedious; and are seldom completed during drill situations. As previously mentioned, the damage control methods in use at the present time assume a minimum knowledge of the hydrostatic and stability condition of the ship. However, a far more efficient method of fighting the flooding hazard is possible given a knowledge of these parameters. The Stability Module performs the required calculations and provides the state of the ship to the crew. This allows the development of more effective damage control methods and increases the "corporate knowledge" of the damage control team. As more scenarios of damage are run to completion, the ability of the crew to fight flooding increases. Also the Module's ability to demonstrate, in real terms, the consequences of parameters such as MTI, GM, and others makes it an invaluable training aid ashore and during training exercises

afloat. In conclusion, the further development of the Damage Control Stability Module is highly recommended.

A final comment on the usage of the Module is in order. The purpose of the Module is to aid the Damage Control Officer in the execution of damage control procedures, not to replace him or relieve him of his responsibilities. The technical data output from this program coupled with the experience of damage control teams should lead to more efficient methods of controlling the flooding hazard.

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18) Naval Ship's Technical Manual, Chapter 079, Volume 1, NAVSEA S9086-CN-STM-010/CH-079 V1

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20) Damage Control Console Technical Manual, NAVSEA 0971-LP-027-8010

APPENDIX A TANK SOUNDING TABLES

The following is a listing of the data file "TKREF DATA."

This file assigns the tanks to an identification number.

1	5-292-3-W
2	5-292-2-W
3	5-308-1-W
4	5-308-2-W
5	3-272-2-F
6	3-278-2-F
7	3-286-2-F
8	4-208-4-F
9	3-236-1-F
10	3-236-2-F
11	3-292-8-F
12	5-56-0-F
13	5-64-0-F
14	5-84-1-F
15	5-84-2-F
16	5-100-3-F
17	5-100-4-F
18	5-116-1-F
19	5-116-2-F
20	5-140-1-F
21	5-140-2-F
22	5-164-3-F
23	5-164-2-F
24	5-204-1-F
25	5-204-2-F
26	5-250-1-F
27	5-250-2-F
28	3-316-1-J
29	3-322-1-J
30	5-328-0-J
31	5-344-0-J
32	5-132-0-F
33	5-170-0-F
34	5-164-0-F
35	5-32-0-W
36	5-116-0-W
37	5-328-1-W
38	5-328-2-W

The following is a listing of the data file "TKCAPS DATA." The format for this file is:

```
     SOUNDING    GALLONS     VCG     LCG      TCG   MOMENT OF INERTIA
0       0                    MINIMUM READING......
1
2
3
4
5    FULL                    MAXIMUM READING......
```

```
1/
0.0,        15.0,       5.2,        -88.0,      9.27,        0.0,
0.5,        75.0,       5.4,        -92.9,      9.35,       10.0,
1.0,       196.0,       5.8,        -94.1,      9.6,        50.0,
1.92,      576.0,       6.4,        -95.0,     10.2,       130.0,
2.5,       901.0,       6.75,       -95.3,     10.5,       150.0,
3.81,     1599.0,       7.44,       -95.6,     10.63,       99.0/

2/
0.0,        31.0,       5.4,        -88.0,     -8.94,        0.0,
0.5,       114.0,       5.54,       -93.55,    -9.32,       20.0,
0.92,      230.0,       5.86,       -94.3,     -9.7,        60.0,
1.83,      634.0,       6.45,       -95.05,   -10.26,      130.0,
2.75,     1149.0,       7.0,        -95.5,    -10.6,       145.0,
3.625,    1593.0,       7.44,       -95.6,    -10.65,       99.0/

3/
0.0,         4.0,       5.93,      -105.75,     8.52,        0.0,
0.75       100.0,       6.4,       -108.3,      8.85,       10.0,
1.5,       343.0,       6.93,      -110.9,      9.23,       90.0,
3.0,      1293.0,       7.9,       -113.05,     9.94,      200.0,
4.5,      1873.0,       8.43,      -114.9,     10.12,      120.0,
5.896,    2121.0,       8.73,      -115.8,     10.2,         0.0/

4/
0.0,         1.0,       5.93,      -105.75,    -8.52,        0.0,
0.75,       62.0,       6.35,      -108.25,    -8.85,       10.0,
1.5,       317.0,       6.9,       -110.8,     -9.2,        70.0,
3.0,      1250.0,       7.85,      -113.0,     -9.91,      200.0,
4.5,      1856.0,       8.4,       -114.9,    -10.1,       130.0,
5.927,    2121.0,       8.73,      -115.8,    -10.2,         0.0/

5/
0.0,         0.0,      10.323,      -67.5,    -19.8          0.0,
0.67        19.0,      10.7,        -70.6,    -19.6          2.0,
1.65,      125.0,      11.45,       -70.7,    -19.4,        15.0,
3.3,       400.0,      12.4,        -70.7,    -19.4,        32.0,
5.0,       735.0,      13.33,       -70.7,    -19.5,        45.0,
6.6,      1081.0,      14.24,       -70.7,    -19.61,       53.0/
```

```
6/
0.0,        0.0,     10.4,      -74.0,    -19.95,      0.0,
1.0,       50.0,     10.55,     -77.8,    -19.2,       7.0,
1.625,    138.0,     11.5,      -77.9,    -19.12,     15.0,
3.25,     445.0,     12.48,     -77.9,    -19.2,      32.0,
4.875,    825.0,     13.4,      -77.9,    -19.35,     46.0,
6.5,     1233.0,     14.29,     -77.9,    -19.48,     56.0/

7/
0.0,        0.0,     10.53,     -82.0,    -19.2,       0.0,
1.0,       30.0,     11.14,     -84.85,   -18.95,      4.0,
1.625,     82.0,     11.5,      -84.9,    -18.9,       9.0,
3.25,     300.0,     12.5,      -84.95,   -19.0,      18.0,
4.875,    557.0,     13.4,      -84.95,   -19.18,     27.0,
6.5,      802.0,     16.9,      -84.95,   -19.33,     36.0/

8/
0.0,        0.0,      4.0,       -6.0,     -5.0,       0.0,
1.0,       57.0,      4.5,       -6.0,     -5.0,       2.6,
1.25,      67.0,      4.67,      -6.0,     -5.0,       2.6,
2.5,      146.0,      5.25,      -6.0,     -5.0,       2.6,
3.75,     220.0,      5.86,      -6.0,     -5.0,       2.6,
5.0,      293.0,      6.5,       -6.0,     -5.0,       2.6/

9/
0.0,        0.0,     11.84,     -35.0,     21.9,       0.0,
0.26,       2.0,     11.95,     -33.95,    21.69,      1.0,
1.26,      26.0,     12.65,     -33.87,    21.2,       3.5,
2.52,     140.0,     13.3,      -33.87,    21.19,      5.12,
3.78,     230.0,     13.55,     -33.87,    21.21,      6.5,
5.04,     323.0,     14.67,     -33.87,    21.29,      7.1/

10/
0.0,        0.0,     11.84,     -35.0,    -21.9,       0.0,
0.26,       2.0,     11.95,     -33.95,   -21.69,      1.0,
1.26,      26.0,     12.65,     -33.87,   -21.2,       3.5,
2.52,     140.0,     13.3,      -33.87,   -21.19,      5.12,
3.78,     230.0,     13.55,     -33.87,   -21.21,      6.5,
5.04,     323.0,     14.67,     -33.87,   -21.29,      7.1/

11/
0.0,        0.0,     11.0,      -89.3,    -16.82,      0.0,
0.75,      35.0,     11.37,     -89.3,    -17.01,      4.1,
1.5,       70.0,     11.75,     -89.3,    -17.07,      4.5,
3.0,      151.0,     12.55,     -89.3,    -17.05,      5.5,
4.5,      238.0,     13.35,     -89.3,    -16.98,      6.0,
6.25,     281.0,     13.73,     -89.3,    -16.92,      6.3/

12/
0,         50.0,      0.15,     143.95,     0.0,      23.0,
1,        336.0,      0.86,     143.91,     0.0,     187.0,
3,       1332.0,      2.0,      143.91,     0.0,     729.0,
4.5,     2320.0,      2.9,      143.91,     0.0,    1189.0,
6,       3461.0,      3.81,     143.91,     0.0,    1648.0,
7.885,   4938.0,      4.79,     143.91,     0.0,    2308.0/
```

```
13/
 0.0,        78.0,       0.2,        129.8,      0.0,         46.0,
 1.0,       621.0,       0.65,       129.7,      0.0,        479.0,
 2.5,      2025.0,       1.34,       129.66,     0.0,       1707.0,
 5.0,      5396.0,       2.48,       129.62,     0.0,       4440.0,
 7.5,      9650.0,       3.61,       129.59,     0.0,       7448.0,
10.0,     14100.0,       4.62,       129.7,      0.0,      10800.0/

14/
 0,          96.0,       0.35,       111.92,     0.91,        21.0,
 2.5,       683.0,       1.14,       111.85,     1.97,       211.0,
 7.0,      2968.0,       2.74,       111.82,     3.31,       920.0,
14,        7914.0,       5.13,       111.81,     4.51,      2033.0,
18,       12164.0,       6.83,       111.8,      5.06,      2684.0,
23,       18900.0,       9.2,        111.86,     5.64,      3830.0/

15/
 0,          34.0,       0.2,        111.95,    -0.62,         6.0
 2.12,      780.0,       1.2,        111.85,    -2.1,        225.0,
 5.4,      3000.0,       2.74,       111.82,    -3.3,        920.0,
10.5       7871.0,       5.11,       111.81,    -4.5,       2028.0,
14.1,     12020.0,       6.76,       111.8,     -5.06,      2784.0,
19.15,    18900.0,       9.2,        111.83,    -5.64,      3830.0/

16/
 0,          10.0,       0.15,        92.0,      0.52,         2.0,
 2,         461.0,       1.27,        91.98,     2.37,       192.0,
 4.5,      1937.0,       2.83,        93.01,     4.33,       841.0,
 7.0,      3744.0,       4.17,        92.76,     5.1,       1317.0,
11.5,      7422.0,       6.65,        92.36,     6.02,      2171.0,
15.41,    10891.0,       8.77,        92.95,     6.6,       2950.0/

17/
 0,          10.0,       0.5,         92.0,     -0.52,         2.0,
 2.0,       424.0,       1.21,        91.98,    -2.29,       172.0,
 4.0,      1360.0,       2.34,        92.73,    -3.81,       694.0,
10.5,      5474.0,       5.42,        92.5,     -5.61,      1772.0,
13.0,      7484.0,       6.7,         92.36,    -6.04,      2189.0,
16.82,    10891.0,       8.77,        92.25,    -6.6,       2950.0/

18/
 0,          10.0,       1.15,        73.04,     4.72,         1.0,
 2.0,       669.0,       2.11,        75.27,     5.99,       161.0,
 4.5,      2616.0,       3.29,        75.42,     7.16,       799.0,
 8.5,      7254.0,       5.09,        75.49,     8.32,      2060.0,
12.5,     13229.0,       6.9,         75.53,     9.09,      3270.0,
17,       22300.0,       9.24,        75.7,      9.78,      4900.0/

19/
 0,          46.0,       1.3,         74.36,    -4.93,         4.0,
 1.5,       651.0,       2.1,         75.29,    -5.97,       158.0,
 3.5,      2458.0,       3.21,        75.41,    -7.1,        748.0,
 7.0,      7604.0,       5.21,        75.49,    -8.38,      2139.0,
10.5,     14247.0,       7.18,        75.53,    -9.19,      3449.0,
14.4      22300.0,       9.24,        75.7,     -9.78,      4900.0/
```

```
20/
 0.0,      284.0,       0.49,         51.89,      1.33,       112.0,
 0.5,      626.0,       0.81,         51.87,      1.98,       356.0,
 2.0,     2826.0,       1.76,         51.83,      3.59,      2034.0,
 3.5,     5920.0,       2.69,         51.81,      4.79,      4451.0,
 4.0,     7089.0,       2.99,         51.81,      5.10,      4566.0,
 5.167,   9644.0,       3.61,         51.83,      5.46,         0.0/

21/
 0.0,      313.0,       0.52,         51.89,     -1.39,       127.0,
 0.5,      750.0,       0.84,         51.87,     -2.04,       385.0,
 1.5,     2085.0,       1.47,         51.84,     -3.15,      1402.0,
 2.5,     3851.0,       2.1,          51.82,     -4.06,      2881.0,
 4.0,     7187.0,       3.02,         51.81,     -5.12,      4542.0,
 5.167,   9644.0,       3.61,         51.83,     -5.46       3993.0/

22/
 0.0,       72.0,       1.5,          31.65,      6.20,        11.0,
 0.5,      218.0,       1.8,          31.84,      6.66,        56.0,
 1.0,      444.0,       2.12,         31.94,      7.15,       165.0,
 2.0,     1107.0,       2.75,         31.98,      8.09,       526.0,
 3.0,     1998.0,       3.37,         31.98,      8.82,       794.0,
 4.33,    3155.0,       3.97,         31.99,      9.11,       629.0/

23/
 0.0,       50.0,       1.43,         31.58,     -6.09,         7.0,
 0.5,      167.0,       1.7,          31.62,     -6.55,        35.0,
 1.5,      641.0,       2.29,         31.85,     -7.47,       249.0,
 2.5,     1405.0,       2.9,          31.86,     -8.28,       645.0,
 3.5,     2365.0,       3.48,         31.88,     -8.85,       783.0,
 4.583,   3373.0,       4.04,         31.89,     -9.08,       643.0/

24/
 0.0,       30.0,       1.57,         -3.93,      6.66,         5.0,
 3.0,      731.0,       3.01,         -3.98,      8.89,       370.0,
 6.0,     2099.0,       4.41,         -3.99,     10.41,      1147.0,
11.5,     5472.0,       6.83,         -4.0,      12.01,      2345.0,
17.5,     9914.0,       9.45,         -4.0,      12.91,      2954.0,
23.583,  15750.0,      12.65,         -4.0,      13.48,      3240.0/

25/
 0.0,       38.0,       1.61,         -3.93,     -6.73,         7.0,
 3.0,      695.0,       2.97,         -3.98,     -8.83,       348.0,
 6.0,     1931.0,       4.27,         -3.99,    -10.28,      1064.0,
11.5,     4995.0,       6.53,         -4.0,     -11.87,      2228.0,
17.5,     9160.0,       9.05,         -4.0,     -12.81,      2895.0,
23.417,  15750.0,      12.65,         -4.0,     -13.48,      3240.0/

26/
 0,         61.0,       0.25,        -56.48,      0.62,        10.0,
 1.0,      663.0,       0.9,         -57.8,       1.65,       234.0,
 2.,      1834.0,       1.55,        -58.36,      2.59,       836.0,
 4.,      5422.0,       2.79,        -59.23,      4.02,      2720.0,
 6.,      7603.0,       3.95,        -59.73,      5.04,      3592.0,
 6.75,   11389.0,       4.33,        -59.82,      5.19,      3331.0/
```

```
27/
 0,          39.0,       0.20,        -56.03,    -0.54,         6.0,
 1.0,       597.0,       0.85,        -57.75,    -1.58,       202.0,
 2.,       1740.0,       1.50,        -58.32,    -2.52,       780.0,
 4.,       5319.0,       2.75,        -59.21,    -3.98,      2634.0,
 6.,       9784.0,       3.92,        -59.72,    -5.02,      3613.0,
 6.75,    11389.0,       4.33,        -59.82,    -5.19,      3331.0/

28/
 0.0,         0.0,       9.51,       -113.05,    15.54,         0.0,
 1.0,        44.0,      10.14,       -114.67,    15.56,         4.0,
 2.5,       221.0,      11.01,       -114.42,    15.84,        22.0,
 4.5,       526.0,      12.05,       -114.84,    16.33,        40.0,
 8.0,      1220.0,      13.95,       -114.86,    16.87,        84.0,
 8.67,     1341.0,      14.24,       -114.87,    16.92,        45.0/

29/
 0.0,         1.0,       9.18,       -119.46,    14.50,         0.0,
 1.0,        50.0,      10.43,       -120.66,    15.23,         4.0,
 2.0,       167.0,      11.03,       -120.79,    15.49,        22.0,
 4.0,       454.0,      12.04,       -120.85,    16.0,         29.0,
 6.0,       311.0,      13.11,       -120.85,    16.40,        53.0,
 8.33,     1284.0,      14.34,       -120.87,    16.71,        76.0/

30/
 0.0         89.0,       6.17,       -127.87,     0.0,        345.0,
 0.5,       389.0,       6.49,       -129.13,     0.0,       1150.0,
 1.5,      1571.0,       7.12,       -130.58,     0.0,       3412.0,
 3.0,      4043.0,       7.93,       -131.38,     0.0,       4410.0,
 5.75,     8860.0,       9.3,        -131.74,     0.0,       4410.0,
 6.167,    9185.0,       9.43,       -131.84,     0.0,       2051.0/

31/
 0.0,         7.0,       7.05,       -140.88,     0.0,          6.0,
 1.0,       126.0,       7.51,       -142.39,     0.0,        219.0,
 2.0,       544.0,       7.96,       -144.02,     0.0,       1433.0,
 4.5,      3783.0,       9.44,       -149.46,     0.0,       6615.0,
 6.5,      8278.0,      10.38,       -150.69,     0.0,       6615.0,
 7.83,    10351.0,      10.57,       -151.12,     0.0,       2605.0/

32/
 0.0,        44.0,       0.22,         68.03,    -0.02,        37.0,
 1.25,      317.0,       0.70,         68.25,    -0.27,       379.0,
 4.5,      1232.0,       1.72,         68.33,    -0.39,       379.0,
 9.0,      2642.0,       3.25,         68.34,    -0.41,       379.0,
13.5,      4546.0,       5.31,         68.35,    -0.42,       379.0,
18.0,      6514.0,       7.46,         68.36,    -0.42,         0.0/

33/
 0.0,        94.0,       0.29,         28.98,     0.0,        121.0,
 0.5,       370.0,       0.60,         28.98,     0.0,        763.0,
 2.5,      1949.0,       1.67,         29.0,      0.0,       1087.0,
 3.5,      2743.0,       2.17,         29.0,      0.0,       1087.0,
 4.5,      3536.0,       2.67,         29.0,      0.0,       1087.0,
 5.58,     4348.0,       3.18,         29.0,      0.0,       1087.0/
```

```
34/
 0.0,        21.0,         0.17,          36.99,     0.0,         19.0,
 1.0,       367.0,         0.81,          36.99,     0.0,        652.0,
 2.0,       847.0,         1.35,          37.0,      0.0,        652.0,
 3.5,      1502.0,         2.08,          37.97,    -0.04,       579.0,
 4.5,      1897.0,         2.52,          37.91,    -0.12,       579.0,
 5.67,     2383.0,         3.05,          37.86,    -0.18,       579.0/

35/
 0,         145.0,         0.36,         161.78,     0.0,         31.0,
 1,         665.0,         0.97,         161.66,     0.0,        169.0,
 2.5,      1849.0,         1.87,         161.61,     0.0,        470.0,
 4.5,      3910.0,         3.06,         161.59,     0.0,        908.0,
 6.5,      6351.0,         4.24,         161.6,      0.0,       1356.0,
 8.33,     8395.0,         5.12,         161.75,     0.0,       1850.0/

36/
 0,          54.0,         0.17,          79.98,     0.0,         42.0,
 1,         856.0,         0.8,           79.95,     0.0,        953.0,
 4,        4023.0,         2.34,          79.99,     0.0,        953.0,
 7.5,      7718.0,         4.1,           79.99,     0.0,        953.0,
11,       11941.0,         5.85,          80.0,      0.0,        953.0,
14.83,    15182.0,         7.64,          80.04,     0.0,        953.0/

37/
 0,           1.0,         7.03,        -126.09,     6.54,         2.0,
 0.5,        20.0,         7.4,         -126.23,     7.41,        10.0,
 1.5,       204.0,         8.18,        -128.87,     8.68,        71.0,
 3,        1382.0,         9.3,         -134.01,     9.74,       572.0,
 4.5,      3788.0,        10.31,        -138.73,    10.2,        704.0,
 5.83,     5107.0,        10.75,        -141.12,    10.24,       300.0/

38/
 0,           1.0,         7.00,        -126.18,    -6.49,         2.0,
 0.5,        15.0,         7.38,        -126.17,    -7.36,         9.0,
 1.5,       108.0,         8.16,        -128.78,    -8.65,        68.0,
 3,        1365.0,         9.29,        -133.98,    -9.74,       567.0,
 4.5,      3763.0,        10.30,        -138.70,   -10.24,       706.0,
 5.83,     5107.0,        10.75,        -141.12,   -10.24,       300.0/
```

APPENDIX B   COMPARTMENT SOUNDING TABLES

The following is a listing of the data file "FLXREF DATA." This file assigns an identification number (30-60) to each watertight subdivision. The format for the first line of each line item is:

LINE (I2), REPAIR LOCKER (I2), HEIGHT ABOVE BASELINE (F4.1).

The following lines of each item detail the compartment number, description, and system code.

```
300117.0
3-32-1-K     FLAM LIQ STRM       70
3-32-2-A     DECK GR STRM        70
3-40-2-A     CPO STOREROOM       60
3-43-0-L     PASSAGEWAY          90
3-46-1-A     SPE CLOTH STRM      70
3-46-3-A                         90
3-48-2-A     XO STOREROOM        90
3-53-2-A     SMALL ST STRM       60
3-56-0-A     DECK GR STRM        70
3-59-2-A     MAA STOREROOM       90

310116.0
3-64-1-V     VOID                90

320116.0
3-64-2-V     VOID.               90

330116.0
3-64-0-M     MK13 MAGAZINE       40

340115.8
3-84-0-E     AC MACH ROOM        20
3-84-1-T     ESCAPE TRUNK        20

350115.0
3-100-0-L    DRESSING SPACE      60
3-100-1-L    LOUNGE              60
3-113-0-L    CREWS HEAD          60
3-124-0-L    BERTHING            60

360114.0
3-140-1-L    CREWS HEAD          60
3-140-1-L    PASSAGEWAY          60
3-140-2-L    LOUNGE              60
```

3-144-0-L	DRESSING SPACE	60
3-154-1-Q	PIPING	20
3-154-2-Q	PIPING	20
3-162-0-L	BERTHING	60
370313.0		
3-180-0-A	FREEZE STRM	60
3-180-1-A	CHILL STRM	60
3-180-3-A	CHILL STRM	60
3-180-5-A	DRY PROV STRM	60
3-180-2-C	SWITCH GEAR	30
3-188-0-L	PASSAGEWAY	60
3-196-2-A	SHIP ST STRM	60
380811.7		
3-292-2-E	SSDG NR 4	30
390211.7		
3-328-0-A	GSK STOREROOM	60
40014.0		
4-H-0-V	VOID	90
41014.0		
4-20-0-W	SUMP	90
42014.0		
4-27-0-V	VOID	90
43018.25		
4-32-0-Q	SONAR EQUIP RM	40
4-48-1-Q	SR COOLING EQUIP	40
44018.0		
4-48-2-L	PASSAGEWAY	90
45018.0		
4-56-1-M	SM ARMS MAG	40
46018.0		
4-56-2-A	DECK GR STRM	70
47017.5		
4-64-0-Q	MAG SVC ROOM	40
4-77-0-Q	PLENUM	40
48035.0		
4-100-0-3	APU MACHINERY	20
49017.0		
4-140-0-Q	LAUNDRY	60
4-140-1-L	PASSAGEWAY	60
4-140-3-A	LAUNDRY STRM	60
4-144-1-5	ACCESS TRUNK	60
4-152-1-A	CW EQUIP ROOM	90
4-160-0-Q	SEWAGE TRTMT	90

50016.0		
4-170-0-W	CONT HLDG TANK	90
51016.0		
4-172-1-E	FIRE PUMP ROOM	11
52064.0		
5-180-0-E	AUX MACH NR 1	20
5-180-01-E	SSDG NR 1	30
5-208-2-T	ESCAPE TRUNK	20
53070.0		
5-212-0-E	AUX MACH NR2	20
5-226-1-E	SSDG NR 3	30
5-226-2-E	SSDG NR 2	30
54050.0		
5-250-0-E	ENGINEROOM	20
55082.0		
5-292-0-E	AUX MACH NR 3	20
561013.0		
5-368-01-E	STEERING GEAR	20
57029.2		
5-368-0-V	VOID	90
580211.0		
5-386-0-V	VOID	90
590212.0		
5-392-0-V	VOID	90
60090.0		
5-51-0-Q	EDUCTOR ROOM	20

The following is a listing of the data file "FLCAPS DATA."

The format for this file is:

```
     SOUNDING    GALLONS     VCG     LCG      TCG   MOMENT OF INERTIA
0       0                    MINIMUM READING......
1
2
3
4
5    FULL                    MAXIMUM READING......
```

```
30/
 0.0,        0.0,      17.0,        154.32,     0.0,      11831.33,
 1.7,     6321.5,      17.93,       154.38,     0.0,      15397.19,
 2.55,    9677.08,     18.45,       154.4,      0.0,      17423.4,
 4.25,   16777.98,     19.6,        154.45,     0.0,      21995.75,
 6.8,    28398.36,     21.54,       154.52,     0.0,      30254.1,
 8.5,    36803.27,     22.97,       154.56,     0.0,      36770.67/

31/
 0.0,        0.0,      16.0,        128.0,     11.6,         81.67,
 1.7,      725.9,      17.0,        128.25,    12.0,         99.22,
 2.55,    1155.67,     17.6,        128.35,    12.2,        113.48,
 4.25,    2148.98,     18.94,       128.52,    12.5,        155.26,
 5.95,    3320.57,     20.42,       128.66,    12.9,        217.68,
 8.5,     5412.24,     22.83,       128.82,    13.4,        357.66/

32/
 0.0,        0.0,      16.0,        128.0,    -11.6,         81.67,
 1.7,      725.9,      17.0,        128.25,   -12.0,         99.22,
 2.55,    1155.67,     17.6,        128.35,   -12.2,        113.48,
 4.25,    2148.89,     18.94,       128.5,    -12.5,        155.26,
 5.95,    3320.57,     20.42,       128.66,   -12.9,        217.68,
 8.5,     5412.24,     22.83,       128.82,   -13.4,        357.66/

33/
 0.0,        0.0,      16.0,        130.0,      0.0,      11431.67,
 1.7,     3871.36,     16.85,       130.0,      0.0,      11431.67,
 2.55,    5807.04,     17.27,       130.0,      0.0,      11431.67,
 4.25,    9678.37,     18.12,       130.0,      0.0,      11431.67,
 6.8,    15485.36,     19.4,        130.0,      0.0,      11431.67,
 8.5,    19356.72,     20.25,       130.0,      0.0,      11431.67/

34/
 0.0,        0.0,      15.8,        111.81,     0.0,      28864.0,
 1.7,     4961.94,     16.67,       111.82,     0.0,      33151.83,
 2.55,    7527.35,     17.12,       111.82,     0.0,      35444.05,
 4.25,   12827.01,     18.06,       111.83,     0.0,      40335.87,
 6.8,    21198.66,     19.53,       111.84,     0.0,      48474.36,
 8.5,    27061.20,     20.56,       111.85,     0.0,      54459.0/
```

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35/
 0,          0.0,       15.0,          83.3,       0.0,          0.0,
 1,       9758.0,       15.5,          83.2,       0.0,     141682.0,
 2,      19683.0,       16.0,          83.3,       0.0,     146144.0,
 4,      40135.0,       17.0,          83.3,       0.0,     157708.0,
 6,      61268.0,       18.1,          83.4,       0.0,     177990.0,
 8.5,    88825.0,       19.4,          83.4,       0.0,     194161.0/

36/
 0.0,        0.0,       14.0,          43.67,      0.0,     211840.0,
 1.7,    19514.01,      14.86,         43.69,      0.0,     222729.83,
 2.55,   29389.01,      15.31,         43.7,       0.0,     228291.86,
 4.25,   49374.80,      16.21,         43.72,      0.0,     239651.48,
 6.8,    79943.32,      17.61,         43.76,      0.0,     257283.22,
 8.5,   100715.49,      18.58,         43.88,      0.0,     269435.12/

37/
 0.0,        0.0,       13.0,          12.49,      2.12,    110146.1,
 1.7,    10729.24,      13.86,         12.4,       2.13,    112951.8,
 2.55,   16132.01,      14.29,         12.4,       2.13,    114420.6,
 4.25,   27013.85,      15.17,         12.4,       2.17,    117236.5,
 6.8,    43527.44,      16.5,          12.4,       2.15,    122060.86,
 8.5,    54663.67,      17.41,         12.4,       2.16,    127306.2/

38/
 0.0,        0.0,       11.7,        -100.52,   -12.22,       5158.83,
 1.7,     4156.76,      21.58,       -100.55,   -12.54,       6032.38,
 2.55,    5920.73,      13.05,       -100.56,   -12.70,       6504.48,
 4.25,   10114.13,      14.02,       -100.59,   -13.02,       7521.74,
 6.8,    16773.65,      15.57,       -100.62,   -13.5,        9237.37,
 8.5,    21459.53,      16.67,       -100.64,   -13.82,      10513.18/

39/
 0.0,        0.0,       11.7,        -144.0,       0.0,      73173.34,
 1.7,    12642.99,      12.59,       -143.95,      0.0,      93600.44,
 2.55,   19364.87,      13.01,       -143.93,      0.0,     105070.77,
 4.25,   33555.96,      13.8,        -143.89,      0.0,     130686.66,
 6.8,    56806.96,      14.88,       -143.84,      0.0,     176283.31,
 8.5,    73606.52,      15.53,       -143.80,      0.0,     211840.0/

40/
 0.0,        0.0,        9.5,         186.67,      0.0,         10.67,
 2.13,     364.75,      11.0,         187.89,      0.0,         69.72,
 4.25,     985.38,      13.0,         188.25,      0.0,         90.6,
 8.5,     3277.68,      14.5,         191.11,      0.0,        334.22,
13.0,    10435.15,      16.5,         193.78,      0.0,        973.5,
17.5,    19435.44,      18.0,         196.44,      0.0,       4679.1/

41/
 0.0,        0.0,        4.0,         177.3,       0.0,        176.0,
 4.4,     1262.03,       6.32,        177.44,      0.0,        434.92,
 6.6,     2202.52,       7.26,        177.48,      0.0,        627.61,
11.0,     4141.29,       8.82,        177.55,      0.0,       1164.97,
17.6,     7752.29,      10.59,        177.63,      0.0,       2427.39,
22.0,    10629.59,      11.5,         177.67,      0.0,       3632.75/
```

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42/
 0.0,        0.0,        4.0,         177.3,       0.0,        176.0,
 4.4,     1262.03,       6.32,        177.44,      0.0,        434.92,
 6.6,     2202.52,       7.26,        177.48,      0.0,        627.61,
11.0,     4141.29,       8.82,        177.55,      0.0,       1164.97,
17.6,     7752.29,      10.59,        177.63,      0.0,       2427.39,
22.0,    10629.59,      11.5,         177.67,      0.0,       3632.75/

43/
 0,          0.0,        8.25,        160.4,       1.6,          0.0,
 1,       1451.0,        8.9,         160.4,       1.7,       3610.0,
 2,       2947.0,        9.4,         160.5,       1.7,       4185.0,
 4,       6188.0,       10.4,         160.6,       1.7,       5100.0,
 6,       9745.0,       11.5,         160.7,       1.8,       6647.0,
 8.5,    14588.0,       12.9,         160.7,       1.9,       8587.0/

44/
 0,          0.0,        8.0,         151.9,      -6.5,          0.0,
 1,        325.0,        8.5,         151.9,      -6.6,        223.0,
 2,        728.5,        9.0,         151.9,      -6.8,        246.0,
 4,       1513.5,       10.0,         151.9,      -7.0,        300.0,
 6,       2356.0,       11.1,         151.9,      -7.4,        347.0,
 8.5,     3494.0,       12.5,         151.9,      -7.8,        426.0/

45/
 0,          0.0,        8.0,         143.9,       3.75,         0.0,
 1,        274.0,        8.5,         143.9,       3.9,        282.0,
 2,        558.0,        9.0,         143.9,       4.0,        317.0,
 4,       1158.0,       10.0,         143.9,       4.3,        394.0,
 6,       1796.0,       11.1,         143.9,       4.6,        481.0,
 8.5,     2651.0,       12.45,        143.9,       4.9,        577.0/

46/
 0,          0.0,        8.0,         143.9,      -3.75,         0.0,
 1,        274.0,        8.5,         143.9,      -3.9,        282.0,
 2,        588.0,        9.0,         143.9,      -4.0,        317.0,
 4,       1158.0,       10.0,         143.9,      -4.3,        394.0,
 6,       1796.0,       11.1,         143.9,      -4.6,        481.0,
 8.5,     2651.0,       12.45,        143.9,      -4.9,        577.0/

47/
 0,          0.0,        7.5,         129.6,       0.0,          0.0,
 1,       2516.0,        8.0,         129.6,       0.0,      11065.0,
 2,       5103.0,        8.5,         129.6,       0.0,      12261.0,
 4,      10609.0,        9.5,         129.6,       0.0,      15136.0,
 6,      16150.0,       10.6,         129.7,       0.0,      18209.0,
 8.5     23777.0,       11.5,         129.7,       0.0,      22665.0/

48/
 0,          0.0,        5.0,         100.0,       0.0,          0.0,
 1,        875.0,        5.5,         100.0,       0.0,       8637.0,
 3,       2703.0,        6.5,         100.0,       0.0,      10381.0,
 5,       4636.0,        7.6,         100.0,       0.0,      12217.0,
 7,       6679.0,        8.6,         100.0,       0.0,      14400.0,
 9.5,     9380.0,       10.0,         100.0,       0.0,      17476.0/
```

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49/
 0,          0.0,       7.0,         46.0,     -0.8,         0.0,
 1,       7419.0,       7.5,         46.0,     -0.9,     94141.0,
 2,      15100.0,       8.0,         46.0,     -0.9,    100186.0,
 4,      31225.0,       9.1,         46.0,     -1.0,    119690.0,
 6,      48438.0,      10.1,         46.0,     -1.0,    142699.0,
 8.5,    71296.0,      11.4,         46.0,     -1.1,    168840.0/

50/
 0.0,        0.0,       5.83,        32.3,     -0.3,      1016.0,
 6.5,      250.0,       6.22,        30.8,      0.21,     1016.0,
 7.0,      600.0,       6.52,        30.2,      0.35,     1016.0,
 8.0,     1250.0,       7.05,        29.85,     0.39,     1016.0,
 9.0,     1900.0,       7.55,        29.75,     0.40,     1016.0,
10.9,     3101.0,       8.50,        29.71,     0.41,     1016.0/

51/
 0.0,        0.0,       6.0,         27.97,    11.96,      616.2,
 1.5,      823.21,      6.77,        27.97,    12.37,      792.79,
 2.25,    1260.34,      7.16,        27.97,    12.57,      892.41,
 3.75,    2186.80,      7.97,        27.98,    12.98,     1115.82,
 5.25,    3181.72,      8.8,         27.98,    13.39,     1373.45,
 7.5,     4803.45,     10.08,        27.99,    14.0,      1829.33/

52/
 0.0,        0.0,       0.0,         10.59,     0.0,     47408.5,
 1.7,     8833.63,      0.823,       10.06,     0.0,     63617.5,
 2.55,   13541.40,      1.21,        10.1,      0.0,     72922.5,
 4.25,   23543.14,      1.93,        10.18,     0.0,     94411.0,
 5.95,   34323.32,      2.60,        10.25,     0.0,    119732.5,
 8.5,    51957.18,      3.50,        10.35,     0.0,    165713.5/

53/
 0.0,        0.0,       0.0,        -26.8,      0.0,     94056.34,
 4.1,    32238.92,      1.93,       -26.82,     0.0,    124262.42,
 6.15,   49476.9,       2.84,       -26.84,     0.0,    141512.19,
10.3,    86185.11,      4.52,       -26.86,     0.0,    180621.12,
16.4,   146818.52,      6.8,        -26.9,      0.0,    251755.94,
20.5,   190967.57,      8.16,       -26.92,     0.0,    308230.66/

54/
 0.0,        0.0,       6.0,        -66.13,     0.0,    110208.0,
 4.6,    41210.88,      8.11,       -66.75,     0.0,    146758.05,
 6.9,    63199.55,      9.09,       -66.31,     0.0,    167497.59,
11.5,   109948.14,     10.93,       -66.41,     0.0,    214157.56,
18.4,   186984.81,     13.43,       -66.56,     0.0,    297855.53,
23.0,   242958.15,     14.73,       -66.65,     0.0,    363380.5/

55/
 0.0,        0.0,       3.5,       -107.6,      0.88,    41637.5,
 2.8,    13172.22,      4.95,      -106.94,     1.8,     43003.1,
 4.2,    20300.65,      5.72,      -107.02,     2.02,    45863.0,
 7.0,    35643.11,      7.32,      -107.18,     2.44,    68316.7,
 9.8,    52432.25,      9.0,       -107.31,     2.86,    85123.7,
14.0,    80328.77,     11.64,      -107.49,     3.12,   119310.9/
```

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56/
 0.0,         0.0,      14.0,       -183.75,     0.0,      65353.34,
 1.5,     11247.13,     14.83,      -183.71,     0.0,      77454.88,
 2.25,    17110.59,     15.22,      -183.69,     0.0,      84009.26,
 3.75,    29327.4,      15.98,      -183.66,     0.0,      98170.0,
 6.0,     48867.21,     17.05,      -183.6,      0.0,     122175.53,
 7.5,     62700.13,     17.71,      -183.57,     0.0,     140126.67/

57/
 0.0,         0.0,      10.0,       -170.0,      0.0,       6750.0,
 0.6,      1616.11,     10.3,       -170.0,      0.0,       6750.0,
 0.9,      2426.97,     10.45,      -170.0,      0.0,       6750.0,
 1.5,      4045.89,     10.75,      -170.0,      0.0,       6750.0,
 2.1,      5663.13,     11.05,      -170.0,      0.0,       6750.0,
 3.0,      8091.79,     11.5,       -170.0,      0.0,       6750.0/

58/
 0.0,         0.0,      12.0,       -192.0,      0.0,       3201.33,
 0.4,       589.21,     12.2,       -192.0,      0.0,       3201.33,
 0.6,      1470.21,     12.3,       -192.0,      0.0,       3201.33,
 1.0,      1891.08,     12.5,       -192.0,      0.0,       3201.33,
 1.6,      2348.98,     12.8,       -192.0,      0.0,       3201.33,
 2.0,      2934.82,     13.0,       -192.0,      0.0,       3201.33/

59/
 0.0,         0.0,      12.0,       -192.0,      0.0,       1829.33,
 0.4,       336.69,     12.2,       -192.0,      0.0,       1829.33,
 0.6,       505.04,     12.3,       -192.0,      0.0,       1829.33,
 1.0,       841.73,     12.5,       -192.0,      0.0,       1829.33,
 1.6,      1341.15,     12.8,       -192.0,      0.0,       1829.33,
 2.0,      1677.84,     13.0,       -192.0,      0.0,       1829.33/

60/
 0.0,         0.0,       0.0,        150.44,     0.0,        900.83,
 1.6,       778.0,       0.86,       150.44,     0.0,        900.83,
 2.4,      1167.19,      1.29,       150.44,     0.0,        900.83,
 4.0,      1947.19,      2.15,       150.44,     0.0,        900.83,
 6.4,      3114.38,      3.45,       150.44,     0.0,        900.83,
 8.0,      3894.38,      4.31,       150.44,     0.0,        900.83/
```
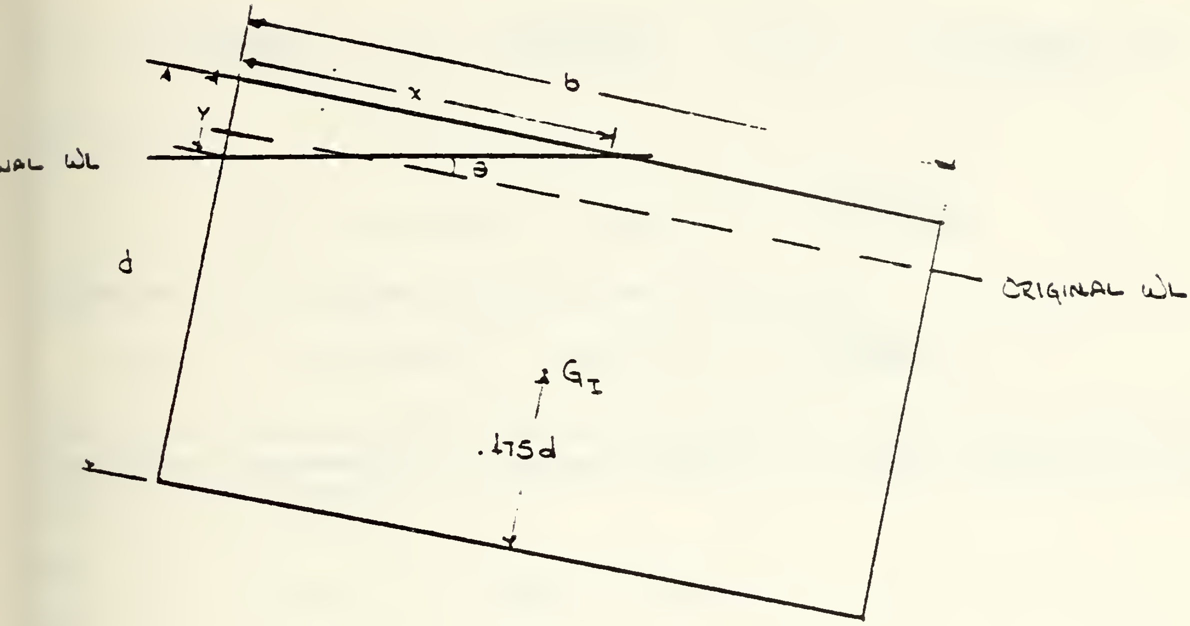

APPENDIX C DERIVATION OF MOMENT OF TRANSFERENCE FACTOR

TANK 95% FULL



Given: $y/x = TAN\theta$ (1)

Area must be conserved during inclination:

$$0.05db = 0.5xy \quad (2)$$

From equation (1)

$$y = xTAN\theta$$

Substituting into equation (2)

$$0.05db = .5x^2 TAN\theta$$

Therefore:

$$x = \sqrt{0.1db/TAN\theta}$$

$$y = \sqrt{0.1db/TAN\theta}$$

Determine center of gravity position for inclined case.
Vertical Center (from baseline):

$$\bar{y} = \{(db - d\sqrt{0.1db/TAN\theta})(0.5d) + 0.05db(d - \sqrt{0.1dbTAN\theta} +$$

$$0.33\sqrt{.1dbTAN\theta}) + 0.5(d\sqrt{.1db/TAN\theta} - .1db)(d - \sqrt{.1dbTAN\theta})\}/.95db$$

Simplifying:

$$\bar{y} = (.45/.95)d + (.01667/.95)\sqrt{.1db/TAN\theta} \tag{3}$$

Likewise the Horizontal Center (from centerline):

$$\bar{x} = (.5 - (.45/.95))b - (.01667/.95)\sqrt{.1db/TAN\theta} \tag{4}$$

These equations hold from the initial wetting of the upper surface to the initial uncovering of the tank bottom. The sine correction applies prior to this point.

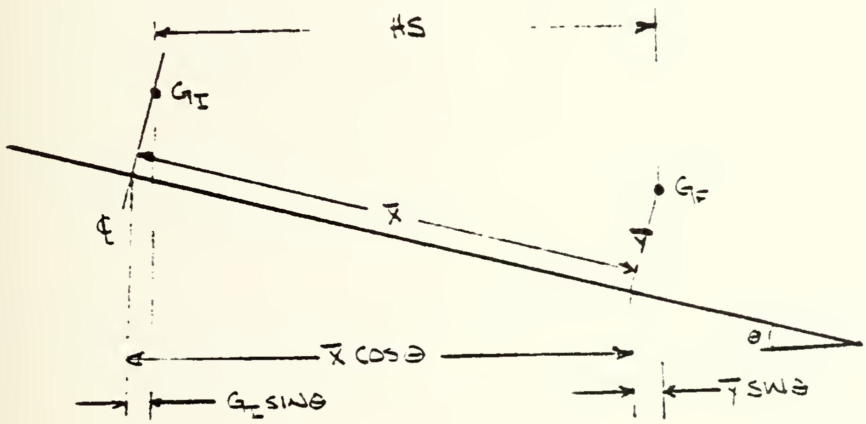
or:

$x = b \qquad TAN\theta = 0.1d/b$

and

$y = d \qquad TAN\theta = 10.0d/b$

Now determine the actual horizontal shift in the center of gravity.



$$\text{Horizontal Shift} = HS = \bar{x}\,COS\theta + (\bar{y} - G_I)SIN\theta$$

Substituting in equations (3) and (4) and:

$$G_I = 0.475d$$

$$HS = (.026316b - .0175439\sqrt{.1db/TAN\theta})COS\theta +$$

$$(.0175439\sqrt{.1dbTAN\theta} - .0013158d)SIN\theta \tag{5}$$

The Moment of Transference is equal to the weight of the liquid in the tank times the horizontal shift in the center of gravity.

Weight of liquid = $.95dbl/\delta$

where: l = length of the tank
δ = density of liquid

The ratio of the Moment of Transference to i_T/δ is the factor, C.

$$C = (HS)(.95dbl/\delta)/(lb^3/12\delta)$$

This yields:

$$C_{95\%} = (.3(d/b) - .2(d/b)\sqrt{(.1/TAN\theta)(d/b))}COS\theta +$$

$$(.2(d/b)\sqrt{.1(d/b)TAN\theta} - .015(d/b)^2)SIN\theta$$

APPENDIX D CROSS CURVE EQUATIONS FOR TRIMS OF +/-15,+/-7.5, AND 0.0 FEET

Equations for +15.0 Feet:

$$RA_{10} = 2.585 - 9.09045 \times 10^{-3}\,\Delta + 1.433 \times 10^{-7}\,\Delta^2 - 7.1 \times 10^{-12}\,\Delta^3$$

$$RA_{20} = 5.428 - 1.907 \times 10^{-3}\,\Delta + 2.583 \times 10^{-7}\,\Delta^2 + 5.614 \times 10^{-12}\,\Delta^3 - 2.3645 \times 10^{-15}\,\Delta^4$$

$$RA_{30} = 1.9237 + 8.421 \times 10^{-4}\,\Delta - 2.082 \times 10^{-7}\,\Delta^2 + 1.0533 \times 10^{-11}\,\Delta^3$$

$$RA_{40} = 3.085 + 6.649 \times 10^{-4}\,\Delta - 2.107 \times 10^{-7}\,\Delta^2 + 1.0733 \times 10^{-11}\,\Delta^3$$

$$RA_{50} = 4.7911 - 1.5051 \times 10^{-4}\,\Delta - 9.31 \times 10^{-8}\,\Delta^2 + 4.9333 \times 10^{-12}\,\Delta^3$$

$$RA_{60} = 7.1518 - 1.765 \times 10^{-3}\,\Delta + 2.122 \times 10^{-7}\,\Delta^2 - 1.38667 \times 10^{-11}\,\Delta^3$$

$$RA_{70} = 6.2394 - 1.4983 \times 10^{-3}\,\Delta + 1.274 \times 10^{-7}\,\Delta^2 - 5.2667 \times 10^{-12}\,\Delta^3$$

$$RA_{80} = 4.43346 - 1.1001 \times 10^{-3}\,\Delta + 6.64 \times 10^{-8}\,\Delta^2 - 4.0 \times 10^{-13}\,\Delta^3$$

$$RA_{90} = 2.0385 - .798234 \times 10^{-3}\,\Delta + .82247 \times 10^{-7}\,\Delta^2 - .31479 \times 10^{-11}\,\Delta^3$$

Equations for +7.5 Feet:

$$RA_{10} = 2.206 - 5.782 \times 10^{-4} \Delta + 2.57 \times 10^{-8} \Delta^2 + 8.965 \times 10^{-12} \Delta^3 - 6.956 \times 10^{-16} \Delta^4$$

$$RA_{20} = 3.0355 - 6.8623 \times 10^{-4} \Delta + 7.76 \times 10^{-8} \Delta^2 + 1.1336 \times 10^{-12} \Delta^3 - 3.8325 \times 10^{-16} \Delta^4$$

$$RA_{30} = 3.3007 - 9.0575 \times 10^{-4} \Delta + 2.775 \times 10^{-7} \Delta^2 - 2.7424 \times 10^{-11} \Delta^3$$

$$RA_{40} = .2492 + 1.844 \times 10^{-3} \Delta - 3.681 \times 10^{-7} \Delta^2 + 1.859 \times 10^{-11} \Delta^3$$

$$RA_{50} = 1.7858 + 1.4286 \times 10^{-3} \Delta - 3.801 \times 10^{-7} \Delta^2 + 2.4104 \times 10^{-11} \Delta^3$$

$$RA_{60} = 4.3819 - 1.0349 \times 10^{-4} \Delta - 1.248 \times 10^{-7} \Delta^2 + 9.9611 \times 10^{-12} \Delta^3$$

$$RA_{70} = 5.4623 - 1.0012 \times 10^{-3} \Delta + 2.66 \times 10^{-8} \Delta^2 + 2.0978 \times 10^{-12} \Delta^3$$

$$RA_{80} = 3.779 - 4.5242 \times 10^{-4} \Delta - 9.15 \times 10^{-8} \Delta^2 + 1.1434 \times 10^{-11} \Delta^3$$

$$RA_{90} = .7414 \times 10^{-2} + .10767 \times 10^{-2} \Delta - .37108 \times 10^{-6} \Delta^2 + .300892 \times 10^{-10} \Delta^3$$

Equations for 0.0 Feet:

$$RA_{10} = .2644 + 4.327 \times 10^{-4} \Delta - 9.14 \times 10^{-8} \Delta^2 - 2.993 \times 10^{-12} \Delta^3 + 1.3534 \times 10^{-15} \Delta^4$$

$$RA_{20} = 1.2309 + 1.197 \times 10^{-4} \Delta - 3.86 \times 10^{-8} \Delta^2 + 3.9114 \times 10^{-12} \Delta^3 + 4.726 \times 10^{-16} \Delta^4$$

$$RA_{30} = 1.5896 - 8.414 \times 10^{-5} \Delta + 6.58 \times 10^{-8} \Delta^2 + 2.0136 \times 10^{-12} \Delta^3 - 1.3547 \times 10^{-15} \Delta^4$$

$$RA_{40} = -.89125 + 1.80111 \times 10^{-3} \Delta - 2.169 \times 10^{-7} \Delta^2 - 6.3813 \times 10^{-12} \Delta^3 + 1.2004 \times 10^{-15} \Delta^4$$

$$RA_{50} = .65476 + 1.432 \times 10^{-3} \Delta - 2.169 \times 10^{-7} \Delta^2 - 1.0082 \times 10^{-11} \Delta^3 + 2.0045 \times 10^{-15} \Delta^4$$

$$RA60 = 3.115 + 3.344 \times 10^{-4} \Delta - 1.495 \times 10^{-7} \Delta^2 + 6.03182 \times 10^{-12} \Delta^3 + 4.4577 \times 10^{-16} \Delta^4$$

$$RA_{70} = 4.13579 - 2.8023 \times 10^{-4} \Delta - 9.26 \times 10^{-8} \Delta^2 + 6.396 \times 10^{-12} \Delta^3 + 4.02165 \times 10^{-16} \Delta^4$$

$$RA_{80} = 3.84127 - 4.559 \times 10^{-4} \Delta - 6.57 \times 10^{-8} \Delta^2 + 2.491 \times 10^{-12} \Delta^3 + 8.336 \times 10^{-16} \Delta^4$$

$$RA_{90} = 2.5513 - .34845 \times 10^{-3} \Delta - .86055 \times 10^{-7} \Delta^2 + 2.491 \times 10^{-12} \Delta^3 + 8.336 \times 10^{-16} \Delta^4$$

Equations for -7.5 Feet:

$$RA_{10} = .28553 + 1.1778 \times 10^{-4} \Delta - 4.6 \times 10^{-9} \Delta^2 - 7.8423 \times 10^{-13} \Delta^3$$

$$RA_{20} = .57232 + 1.8735 \times 10^{-4} \Delta - 7.0 \times 10^{-9} \Delta^2 + 1.8613 \times 10^{-13} \Delta^3$$

$$RA_{30} = .9604 - 6.1408 \times 10^{-5} \Delta + 1.276 \times 10^{-7} \Delta^2 - 1.3564 \times 10^{-11} \Delta^3$$

$$RA_{40} = 1.2647 + 1.7656 \times 10^{-3}\ \Delta - 2.214 \times 10^{-7}\ \Delta^2 + 4.868 \times 10^{-12}\ \Delta^3$$

$$RA_{50} = -.13655 + 1.8156 \times 10^{-3}\ \Delta + 3.468 \times 10\text{-}7\ \Delta^2 + 1.8457 \times 10^{-11}\ \Delta^3$$

$$RA_{60} = 2.8822 + 8.456 \times 10^{-5}\ \Delta - 3.87 \times 10^{-8}\ \Delta^2 - 1.0546 \times 10^{-12}\ \Delta^3$$

$$RA_{70} = 4.449 - 7.801 \times 10^{-4}\ \Delta + 5.55 \times 10^{-8}\ \Delta^2 - 2.8021 \times 10^{-12}\ \Delta^3$$

$$RA_{80} = 4.9623 - 1.3583 \times 10^{-3}\ \Delta + 1.403 \times 10^{-7}\ \Delta^2 - 6.5908 \times 10^{-12}\ \Delta^3$$

$$RA_{90} = 4.9475 - .20515 \times 10^{-2}\ \Delta + .31182 \times 10^{-6}\ \Delta^2 - .19756 \times 10^{-10}\ \Delta^3$$

Equations for -15.0 Feet:

$$RA_{10} = .45023 - 1.0024 \times 10^{-4}\ \Delta + 4.49 \times 10^{-8}\ \Delta^2 - 3.265 \times 10^{-12}\ \Delta^3$$

$$RA_{20} = .44079 + 3.1979 \times 10^{-5}\ \Delta + 5.63 \times 10^{-8}\ \Delta^2 - 5.0748 \times 10^{-12}\ \Delta^3$$

$$RA_{30} = -.07248 + 3.9535 \times 10^{-4}\ \Delta + 6.23 \times 10^{-8}\ \Delta^2 - 1.0506 \times 10^{-11}\ \Delta^3$$

$$RA_{40} = -1.0214 + 1.4861 \times 10^{-3}\ \Delta - 1.559 \times 10^{-7}\ \Delta^2 + 7.6419 \times 10^{-13}\ \Delta^3$$

$$RA_{50} = 1.176 + 6.4976 \times 10^{-4}\ \Delta - 5.01 \times 10^{-8}\ \Delta^2 - 4.4454 \times 10^{-12}\ \Delta^3$$

$$RA60 = 2.241 + 4.3685 \times 10^{-4}\ \Delta - 1.11 \times 10^{-7}\ \Delta^2 + 4.889 \times 10^{-12}\ \Delta^3$$

$$RA_{70} = 3.1987 - 4.5743 \times 10^{-5}\ \Delta - 9.06 \times 10^{-8}\ \Delta^2 + 7.7255 \times 10^{-12}\ \Delta^3$$

$$RA_{80} = 4.7024 - 1.31635 \times 10^{-3}\ \Delta + 1.524 \times 10^{-7}\ \Delta^2 - 7.7692 \times 10^{-12}\ \Delta^3$$

$$RA_{90} = 8.2491 - .45142 \times 10^{-2}\ \Delta + .89675 \times 10^{-6}\ \Delta^2 - .6358 \times 10^{-10}\ \Delta^3$$

APPENDIX E MODULES CHANGED

SUBROUTINE CCEQN

```
C     MODULE NAME: CCEQN FORTRAN
C     A UNIT OF SHIP STABILITY DAMAGE CONTROL SIMULATION
C     BY C. A. BUSH LT USN
C     MIT OCEAN ENGINEER THESIS, SPRING 1984
C     DATE: 23 FEBRUARY 1984
C     -----------------------------------------------------------------
C     PART OF SUBGROUP: SAFETY
C     CALLING MODULES: SUBROUTINE CSSEQN
C     CALLING ARGUMENTS: DISP, TRIM
C     RETURN ARGUMENTS: CCGZ()
C     CALLED MODULES: KGCORR
C     DATA FILES OPENED: NONE
C     DATA FILES CLOSED: NONE
C     DATA FILES USED: NONE
C     PURPOSE OF MODULE: TO COMPUTE THE RIGHTING ARM EVERY 10
C     DEGREES FOR THE PASSED DISPLACEMENT AND TRIM. THE SOURCE OF
C     THE DATA IS NAVSEA PROGRAM 'SHCP'. THE RIGHTING ARM
C     EQUATIONS ARE CUBICS, OR QUARTICS, IN DISPLACEMENT SUCH
C     THAT THE CORRELATION FACTORS ARE GREATER THAN 0.975.
C     -----------------------------------------------------------------
      SUBROUTINE CCEQN(WHEN,DISP,TRIM,CCGZ)
      INTEGER WHEN
      INTEGER A
      INTEGER NOW, FIN
      REAL CCGZ(0:9)
      REAL RA(0:9)
      REAL KGPRI
      REAL LBP,PI,KGO
C
      COMMON/TIMING/NOW,FIN
      COMMON/CONST/LBP,PI,KGO
C
      CALL KGCORR(WHEN,KGPRI)
C
      D = DISP
      D2 = DISP*DISP
      D3 = DISP*DISP*DISP
      D4 = DISP*DISP*DISP*DISP
C
C     DETERMINE THE RIGHTING ARMS TO CALCULATE
C
      IF (TRIM.LT.-15.0) GO TO 200
      IF (TRIM.GE.-15.0.AND.TRIM.LT.-7.5) GO TO 200
      IF (TRIM.GE.-7.5.AND.TRIM.LT.0.0) GO TO 210
      IF (TRIM.GE.0.0.AND.TRIM.LT.7.5) GO TO 220
      IF (TRIM.GE.7.5.AND.TRIM.LT.15.0) GO TO 230
      IF (TRIM.GE.15.0) GO TO 240
C
C     NEGATIVE 15 FOOT RIGHTING ARMS
C
200   RA1N15 = .45023 - 1.0024E-04*D + 4.49E-08*D2 -
     *         3.265E-12*D3
```

```
      RA2N15 = .44079 + 3.1979E-05*D + 5.63E-08*D2 -
     *         5.0748E-12*D3
      RA3N15 = 3.9535E-04*D - .07248 + 6.23E-08*D2 -
     *         1.0506E-11*D3
      RA4N15 = 1.4861E-03*D - 1.0214 - 1.559E-07*D2 +
     *         7.6419E-13*D3
      RA5N15 = 1.176 + 6.4976E-04*D - 5.01E-08*D2 -
     *         4.4454E-12*D3
      RA6N15 = 2.241 + 4.3685E-04*D - 1.11E-07*D2 +
     *         4.8887E-12*D3
      RA7N15 = 3.19866 - 4.5743E-05*D - 9.06E-08*D2 +
     *         7.7255E-12*D3
      RA8N15 = 4.7024 - 1.31635E-03*D + 1.524E-07*D2 -
     *         7.7692E-12*D3
      RA9N15 = 8.2491 - .45142E-02*D + .89675E-06*D2 -
     *         .6358E-10*D3
C
      IF (TRIM + 15.0) 201,201,210
C
201   RA(1) = RA1N15
      RA(2) = RA2N15
      RA(3) = RA3N15
      RA(4) = RA4N15
      RA(5) = RA5N15
      RA(6) = RA6N15
      RA(7) = RA7N15
      RA(8) = RA8N15
      RA(9) = RA9N15
      GO TO 300
C
C     NEGATIVE 7.5 FOOT TRIM RIGHTING ARMS
C
210   RA1N75 = .28553 + 1.1778E-04*D - 4.6E-09*D2 -
     *         7.8423E-13*D3
      RA2N75 = .57232 + 1.8735E-04*D - 7.0E-09*D2 +
     *         1.8613E-13*D3
      RA3N75 = .9604 - 6.1408E-05*D + 1.276E-07*D2 -
     *         1.3564E-11*D3
      RA4N75 = 1.7656E-03*D - 1.2647 - 2.214E-07*D2 +
     *         4.868E-12*D3
      RA5N75 = 1.81555E-03*D - .13655 - 3.468E-07*D2 +
     *         1.8457E-11*D3
      RA6N75 = 2.8822 + 8.456E-05*D - 3.87E-08*D2 -
     *         1.0546E-12*D3
      RA7N75 = 4.449 - 7.801E-04*D + 5.55E-08*D2 -
     *         2.8021E-12*D3
      RA8N75 = 4.9623 - 1.3583E-03*D + 1.403E-07*D2 -
     *         6.5908E-12*D3
      RA9N75 = 4.9475 - .20515E-02*D + .31182E-06*D2 -
     *         .19756E-10*D3
C
      IF (TRIM + 7.5) 213,211,220
C
211   RA(1) = RA1N75
```

```
      RA(2) = RA2N75
      RA(3) = RA3N75
      RA(4) = RA4N75
      RA(5) = RA5N75
      RA(6) = RA6N75
      RA(7) = RA7N75
      RA(8) = RA8N75
      RA(9) = RA9N75
      GO TO 300
C
213   RA(1) = ((RA1N75 - RA1N15)*(TRIM + 15.0)/7.5) + RA1N15
      RA(2) = ((RA2N75 - RA2N15)*(TRIM + 15.0)/7.5) + RA2N15
      RA(3) = ((RA3N75 - RA3N15)*(TRIM + 15.0)/7.5) + RA3N15
      RA(4) = ((RA4N75 - RA4N15)*(TRIM + 15.0)/7.5) + RA4N15
      RA(5) = ((RA5N75 - RA5N15)*(TRIM + 15.0)/7.5) + RA5N15
      RA(6) = ((RA6N75 - RA6N15)*(TRIM + 15.0)/7.5) + RA6N15
      RA(7) = ((RA7N75 - RA7N15)*(TRIM + 15.0)/7.5) + RA7N15
      RA(8) = ((RA8N75 - RA8N15)*(TRIM + 15.0)/7.5) + RA8N15
      RA(9) = ((RA9N75 - RA9N15)*(TRIM + 15.0)/7.5) + RA9N15
      GO TO 300
C
C     0.0 FOOT TRIM LINES
C
220   RA1 = .2644 + 4.327E-04*D - 9.14E-08*D2 -
     *       2.993E-12*D3 + 1.3534E-15*D4
      RA2 = 1.2309 + 1.197E-04*D - 3.86E-08*D2 +
     *       3.9114E-12*D3 + 4.726E-17*D4
      RA3 = 1.5896 - 8.414E-05*D + 6.58E-08*D2 +
     *       2.0136E-12*D3 - 1.3547E-15*D4
      RA4 = 1.80111E-03*D - .89125 - 2.169E-07*D2 -
     *       6.3813E-12*D3 + 1.2004E-15*D4
      RA5 = .65476 + 1.432E-03*D - 2.11E-07*D2 -
     *       1.0082E-11*D3 + 2.0045E-15*D4
      RA6 = 3.115 + 3.344E-04*D - 1.495E-07*D2 +
     *       6.03182E-12*D3 + 4.4577E-16*D4
      RA7 = 4.13579 - 2.8023E-04*D - 9.26E-08*D2 +
     *       6.396E-12*D3 + 4.02165E-16*D4
      RA8 = 3.84127 - 4.559E-04*D - 6.57E-08*D2 +
     *       2.491E-12*D3 + 8.336E-16*D4
      RA9 = 2.5513 - .34845E-03*D - .86055E-07*D2 +
     *       2.491E-12*D3 + 8.336E-16*D4
C
C     IF (TRIM) 223,221,230
C
221   RA(1) = RA1
      RA(2) = RA2
      RA(3) = RA3
      RA(4) = RA4
      RA(5) = RA5
      RA(6) = RA6
      RA(7) = RA7
      RA(8) = RA8
      RA(9) = RA9
      GO TO 300
```

```
C
223   RA(1) = ((RA1 - RA1N75)*(TRIM + 7.5)/7.5) + RA1N75
      RA(2) = ((RA2 - RA2N75)*(TRIM + 7.5)/7.5) + RA2N75
      RA(3) = ((RA3 - RA3N75)*(TRIM + 7.5)/7.5) + RA3N75
      RA(4) = ((RA4 - RA4N75)*(TRIM + 7.5)/7.5) + RA4N75
      RA(5) = ((RA5 - RA5N75)*(TRIM + 7.5)/7.5) + RA5N75
      RA(6) = ((RA6 - RA6N75)*(TRIM + 7.5)/7.5) + RA6N75
      RA(7) = ((RA7 - RA7N75)*(TRIM + 7.5)/7.5) + RA7N75
      RA(8) = ((RA8 - RA8N75)*(TRIM + 7.5)/7.5) + RA8N75
      RA(9) = ((RA9 - RA9N75)*(TRIM + 7.5)/7.5) + RA9N75
      GO TO 300
C
C     7.5 FOOT TRIM RIGHTING ARMS
C
230   RA175 = 2.206 - 5.782E-04*D + 2.57E-08*D2 +
     *        8.965E-12*D3 - 6.956E-16*D4
      RA275 = 3.0355 - 6.8623E-04*D + 7.76E-08*D2 +
     *        1.1336E-12*D3 - 3.8325E-16*D4
      RA375 = 3.3007 - 9.0575E-04*D + 2.775E-07*D2 -
     *        2.7424E-11*D3
      RA475 = .2492 + 1.844E-03*D - 3.681E-07*D2 +
     *        1.859E-11*D3
      RA575 = 1.7858 + 1.4286E-03*D - 3.801E-07*D2 +
     *        2.4104E-11*D3
      RA675 = 4.3819 - 1.0349E-04*D - 1.248E-07*D2 +
     *        9.9611E-12*D3
      RA775 = 5.4623 - 1.0012E-03*D + 2.66E-08*D2 +
     *        2.0978E-12*D3
      RA875 = 3.799 - 4.5242E-04*D - 9.15E-08*D2 +
     *        1.1434E-11*D3
      RA975 = .7414E-02 + .10767E-02*D - .37108E-06*D2 +
     *        .300892E-10*D3
C
C     IF (TRIM - 7.5) 233,231,240
C
231   RA(1) = RA175
      RA(2) = RA275
      RA(3) = RA375
      RA(4) = RA475
      RA(5) = RA575
      RA(6) = RA675
      RA(7) = RA775
      RA(8) = RA875
      RA(9) = RA975
      GO TO 300
C
233   RA(1) = ((RA175 - RA1)*(TRIM + 0.0)/7.5) + RA1
      RA(2) = ((RA275 - RA2)*(TRIM + 0.0)/7.5) + RA2
      RA(3) = ((RA375 - RA3)*(TRIM + 0.0)/7.5) + RA3
      RA(4) = ((RA475 - RA4)*(TRIM + 0.0)/7.5) + RA4
      RA(5) = ((RA575 - RA5)*(TRIM + 0.0)/7.5) + RA5
      RA(6) = ((RA675 - RA6)*(TRIM + 0.0)/7.5) + RA6
      RA(7) = ((RA775 - RA7)*(TRIM + 0.0)/7.5) + RA7
      RA(8) = ((RA875 - RA8)*(TRIM + 0.0)/7.5) + RA8
```

```
      RA(9) = ((RA975 - RA9)*(TRIM + 0.0)/7.5) + RA9
      GO TO 300
C
C     15.0 FOOT TRIM RIGHTING ARMS
C
240   RA115 = 2.585 - 9.09045E-04*D + 1.433E-07*D2 -
     *        7.1E-12*D3
      RA215 = 5.428 - 1.907E-03*D + 2.582E-07*D2 +
     *        5.614E-12*D3 - 2.3645E-15*D4
      RA315 = 1.9237 + 8.421E-04*D - 2.082E-07*D2 +
     *        1.0533E-11*D3
      RA415 = 3.085 + 6.649E-04*D - 2.107E-07*D2 +
     *        1.0733E-11*D3
      RA515 = 4.7911 - 1.5051E-04*D - 9.31E-08*D2 +
     *        4.9333E-12*D3
      RA615 = 7.1518 - 1.765E-03*D + 2.122E-07*D2 -
     *        1.38667E-11*D3
      RA715 = 6.2394 - 1.4983E-03*D + 1.274E-07*D2 -
     *        5.2667E-12*D3
      RA815 = 4.43346 - 1.1001E-03*D + 6.64E-08*D2 -
     *        4.00E-13*D3
      RA915 = 2.0385 - .798234E-03*D + .82247E-07*D2 -
     *        .31479E-11*D3
C
C     IF (TRIM - 15.0) 243,241,241
C
241   RA(1) = RA115
      RA(2) = RA215
      RA(3) = RA315
      RA(4) = RA415
      RA(5) = RA515
      RA(6) = RA615
      RA(7) = RA715
      RA(8) = RA815
      RA(9) = RA915
      GO TO 300
C
243   RA(1) = ((RA115 - RA175)*(TRIM - 7.5)/7.5) + RA175
      RA(2) = ((RA215 - RA275)*(TRIM - 7.5)/7.5) + RA275
      RA(3) = ((RA315 - RA375)*(TRIM - 7.5)/7.5) + RA375
      RA(4) = ((RA415 - RA475)*(TRIM - 7.5)/7.5) + RA475
      RA(5) = ((RA515 - RA575)*(TRIM - 7.5)/7.5) + RA575
      RA(6) = ((RA615 - RA675)*(TRIM - 7.5)/7.5) + RA675
      RA(7) = ((RA715 - RA775)*(TRIM - 7.5)/7.5) + RA775
      RA(8) = ((RA815 - RA875)*(TRIM - 7.5)/7.5) + RA875
      RA(9) = ((RA915 - RA975)*(TRIM - 7.5)/7.5) + RA97.5
      GO TO 300
C
300   CCGZ(0) = 0.0
      DO 400 A = 1,9
      CCGZ(A) = RA(A) + (KGO-KGPRI)*SIN(10.*REAL(A)*PI/180.0)
400   CONTINUE
      RETURN
      END
```

SUBROUTINE CPHYST

```
C       MODULE NAME: CPHYST FORTRAN
C       A UNIT OF SHIP STABILITY DAMAGE CONTROL SIMULATION
C       BY J. R. SANDER LT USN
C       MIT OCEAN ENGINEER THESIS 1983
C       REVISED BY C. A. BUSH LT USN
C       MIT OCEAN ENGINEER THESIS, SPRING 1984
C       DATE: 18 FEBRUARY 1984
C       -------------------------------------------------------------
C       PART OF SUBGROUP: SAFETY
C       CALLING MODULES:  ACHYST,DRHYST,FFHYST
C       CALLING ARGUMENTS:
C       RETURN ARGUMENTS: SHYST() ..SHIP HYDROSTATIC FUNCTIONS
C       CALLED MODULES: KGCORR
C       DATA FILES OPENED: NONE
C       DATA FILES CLOSED: NONE
C       DATA FILES USED: NONE
C       PURPOSE OF MODULE: COMPUTE HYDROSTATICS AS A FUNCTION OF
C       TRIM BASED ON DRAWING 802-4386542 AND OUTPUT OF NAVSEA
C       PROGRAM 'SHCP'.
C       COMPUTES: T,LCB,LCF,KM,MTI,TRIM,TFD,TAFT,GM
C       -------------------------------------------------------------
        SUBROUTINE CPHSYT(SUM,SHYST)
C
        CHARACTER CATID*12
        REAL SUM(6),SHYST(13)
        REAL LCG,LCBN15,LCBN10,LCBN5,LCB0,LCB5,LCB10,LCB15
        REAL KMN15,KMN10,KMN5,KM0,KM5,KM10,KM15
        REAL MTIN15,MTIN10,MTIN5,MTI0,MTI5,MTI10,MTI15
        REAL LCFN15,LCFN10,LCFN5,LCF0,LCF5,LCF10,LCF15
C
        INTEGER SAMT,SWT,SVCG,SLCG,STCG,SFS
        INTEGER HWT,HTMN,HTPI,HLCG,HVCG,HLCF,HLCB,HHA,HGM,MTI,TRIM,
       1 TFD,TAFT
        INTEGER LDTYPE,WATER,LUBE,FUEL,JP5,MISC,BLST,FLOOD,AMMO,
       1 ACFT,PROV,GSTORE,OTHWT,CREW,LSHIP,TOTAL,ALLIQ
        COMMON/XXSUM/SAMT,SWT,SVCG,SLCG,STCG,SFS
        COMMON/HSTATC/HWT,HTMN,HTPI,HLCG,HVCG,HLCF,HLCB,HHA,HGM,
       1 MTI,TRIM,TFD,TAFT
        COMMON/CONST/LBP,PI
C
        REAL KM,KGRISE
C
C       COMPUTE HYDROSTATICS
C
C       COMPUTE TRIM BY DETERMINING TRIM AT WHICH LCB = LCG
C
        LCG = SUM(SLCG)
        DISP = SUM(SWT)
        DISP2 = DISP*DISP
C       DETERMINE LCB FOR GIVEN DISPLACEMENT AT VARIOUS TRIMS
        TN15 = 2.8254 + .0040911*DISP - 1.666E-07*DISP2
              T = TN15
```

```
            T2 = TN15*TN15
      LCBN15 = 81.1137 - 3.7911*T + .036186*T2
C
      TN10 = 3.3584 + .0039062*DISP - 1.566E-07*DISP2
            T = TN10
            T2 = TN10*TN10
      LCBN10 = 71.27 - 3.72433*T + .031437*T2
C
      TN5 = 4.2923 + 3.4086E-03*DISP - 1.0301E-07*DISP2
           T = TN5
           T2 = TN5*TN5
      LCBN5 = 80.9297 - 6.57845*T + .12498*T2
C
      T0 = 4.01838 + 3.35585E-03*DISP - 8.84843E-08*DISP2
          T = T0
          T2 = T0*T0
      LCB0 = 56.83 - 5.714454*T + .11688*T2
C
      T5 = 4.82365 + 2.8762E-03*DISP - 4.2E-08*DISP2
          T = T5
          T2 = T5*T5
      LCB5 = 24.5837 - 4.0275*T + .0892*T2
C
      T10 = 4.309 + 2.94245E-03*DISP - 4.809E-08*DISP2
           T = T10
           T2 = T10*T10
      LCB10 = .028397*T2 - 18.2766 - 1.0887*T
C
      T15 = 3.922 + .002934*DISP - 4.61E-08*DISP2
           T = T15
           T2 = T15*T15
      LCB15 = 1.81125*T - 58.245 - .037689*T2
C
C     DETERMINE TRIM BOUNDS
C
      IF(LCG.LE.LCB15) GO TO 112
      IF(LCG.GT.LCB15.AND.LCG.LE.LCB10) GO TO 113
      IF(LCG.GT.LCB10.AND.LCG.LE.LCB5) GO TO 114
      IF(LCG.GT.LCB5.AND.LCG.LE.LCB0) GO TO 115
      IF(LCG.GT.LCB0.AND.LCG.LE.LCBN5) GO TO 116
      IF(LCG.GT.LCBN5.AND.LCG.LE.LCBN10) GO TO 117
      IF(LCG.GT.LCBN10.AND.LCG.LE.LCBN15) GO TO 118
      IF(LCG.GT.LCBN15) GO TO 119
C
112   TRIM1 = 15.0
      GO TO 180
113   TRIM1 = ((LCG-LCB10)/(LCB15-LCB10))*5.0 + 10.0
      GO TO 170
114   TRIM1 = ((LCG-LCB5)/(LCB10-LCB5))*5.0 + 5.0
      GO TO 160
115   TRIM1 = ((LCG-LCB0)/(LCB5-LCB0))*5.0
      GO TO 150
116   TRIM1 = ((LCG-LCBN5)/(LCB0-LCBN5))*5.0 - 5.0
      GO TO 140
```

```
117   TRIM1 = ((LCG-LCBN10)/(LCBN5-LCBN10))*5.0 - 10.0
      GO TO 130
118   TRIM1 = ((LCG-LCBN15)/(LCBN10-LCBN15))*5.0 - 15.0
      GO TO 120
119   TRIM1 = -15.0
      GO TO 120
C
C     CALCULATE HYDROSTATIC PARAMETERS
C
120   TN15 = 2.8254 + .0040911*DISP - 1.666E-07*DISP2
             T = TN15
             T2 = TN15*TN15
             T3 = TN15*TN15*TN15
      LCBN15 = 81.1137 - 3.7911*T + .036186*T2
      LCFN15 = 259.442 - 44.389*T + 2.69494*T2 - .057608*T3
      KMN15 = 6.843 + 2.762426*T - .176611*T2 + .00397036*T3
      MT1N15 = 485.7155*T - 2239.44 - 30.67813*T2 + .7107294*T3
      TPIN15 = 9.01801*T - 28.698 - .50905*T2 + .0108721*T3
      IF (TRIM1 + 15.0) 123,123,130
123   SHYST(HTMN) = TN15
      SHYST(HLCB) = LCBN15
      SHYST(HLCF) = LCFN15
      KM = KMN15
      SHYST(MTI) = MT1N15
      SHYST(HTPI) = TPIN15
C
130   TN10 = 3.3584 + .0039062*DISP - 1.556E-07*DISP2
             T = TN10
             T2 = TN10*TN10
             T3 = TN10*TN10*TN10
      LCBN10 = 71.27 - 3.72433*T + .031437*T2
      LCFN10 = 21.25965*T - 144.112 + .27298*T2 -
     *         .1322445*T3 + .0040707*T2*T2
      KMN10 = 14.987 + 1.1651*T - .065201*T2 + .001327*T3
      MT1N10 = 111.9826*T - 529.38 - 3.478095*T2 + .0734721*T3
      TPIN10 = .639 + 2.830475*T - .0678706*T2 + .00064404*T3
      IF (TRIM1 + 10.0) 135,133,140
133   SHYST(HTMN) = TN10
      SHYST(HLCB) = LCBN10
      SHYST(HLCF) = LCFN10
      KM = KMN10
      SHYST(MTI) = MT1N10
      SHYST(HTPI) = TPIN10
      GO TO 190
135   SHYST(HTMN) = ((TN10-TN15)*(TRIM1+15.0)/5.0) + TN15
      SHYST(HLCB) = ((LCBN10-LCBN15)*(TRIM1+15.0)/5.0) + LCBN15
      SHYST(HLCF) = ((LCFN10-LCFN15)*(TRIM1+15.0)/5.0) + LCFN15
      KM = ((KMN10-KMN15)*(TRIM1+15.0)/5.0) + KMN15
      SHYST(MTI) = ((MT1N10-MT1N15)*(TRIM1+15.0)/5.0) + MT1N15
      SHYST(TPI) = ((TPIN10-TPIN15)*(TRIM1+15.0)/5.0) + TPIN15
      GO TO 190
C
140   TN5 = 4.2923 + 3.4086E-03*DISP - 1.0301E-07*DISP2
            T = TN5
```

```
       T2 = TN5*TN5
       T3 = TN5*TN5*TN5
      LCBN5 = 80.9297 - 6.57845*T + .12498*T2
      LCFN5 = 90.9372 - 5.76152*T - .44056*T2 + .02269*T3
      KMN5 = 17.073 + .3843*T + .023161*T2 - .001446*T3
      MT1N5 = 97.34413*T - 851.399 + 3.8099*T2 - .21681*T3
      TPIN5 = 2.36111*T - 1.877 + .04909*T2 - .00375*T3
      IF (TRIM1 + 5.0) 145,143,150
143   SHYST(HTMN) = TN5
      SHYST(HLCB) = LCBN5
      SHYST(HLCF) = LCFN5
      KM = KMN5
      SHYST(MTI) = MT1N5
      SHYST(HTPI) = TPIN5
      GO TO 190
145   SHYST(HTMN) = ((TN5-TN10)*(TRIM1+10.0)/5.0) + TN10
      SHYST(HLCB) = ((LCBN5-LCBN10)*(TRIM1+10.0)/5.0) + LCBN10
      SHYST(HLCF) = ((LCFN5-LCFN10)*(TRIM1+10.0)/5.0) + LCFN10
      KM = ((KMN5-KMN10)*(TRIM1+10.0)/5.0) + KMN10
      SHYST(MTI) = ((MT1N5-MT1N10)*(TRIM1+10.0)/5.0) + MT1N10
      SHYST(TPI) = ((TPIN5-TPIN10)*(TRIM1+10.0)/5.0) + TPIN10
      GO TO 190
C
150   T0 = 4.01838 + 3.35585E-03*DISP - 8.84843E-08*DISP2
       T = T0
       T2 = T0*T0
       T3 = T0*T0*T0
      LCB0 = 56.83 - 5.714454*T + .11688*T2
      LCF0 = 138.59 - 26.4097*T + 1.30147*T2 - .0236429*T3
      MT10 = 240.9984*T - 947.8461 - 11.382415*T2 + .1946732*T3
      KM0 = 14.923 + 2.22535*T - .166143*T2 + .003669*T3
      TPI0 = 6.3978*T - 11.853 - .3084225*T2 + .0052717*T3
      IF (TRIM1) 155,153,160
153   SHYST(HTMN) = T0
      SHYST(HLCB) = LCB0
      SHYST(HLCF) = LCF0
      KM = KM0
      SHYST(MTI) = MT10
      SHYST(HTPI) = TPI0
      GO TO 190
155   SHYST(HTMN) = ((T0-TN5)*(TRIM1+5.0)/5.0) + TN5
      SHYST(HLCB) = ((LCB0-LCBN5)*(TRIM1+5.0)/5.0) + LCBN5
      SHYST(HLCF) = ((LCF0-LCFN5)*(TRIM1+5.0)/5.0) + LCFN5
      KM = ((KM0-KMN5)*(TRIM1+5.0)/5.0) + KMN5
      SHYST(MTI) = ((MT10-MT1N5)*(TRIM1+5.0)/5.0) + MT1N5
      SHYST(TPI) = ((TPI0-TPIN5)*(TRIM1+5.0)/5.0) + TPIN5
      GO TO 190
C
160   T5 = 4.82365 + 2.8762E-03*DISP - 4.2E-08*DISP2
       T = T5
       T2 = T5*T5
       T3 = T5*T5*T5
      LCB5 = 24.5837 - 4.0275*T + .0892*T2
      LCF5 = 18.596*T - 140.007 - 1.0057*T2 + .018*T3
```

```
      KM5 = 108.1114 - 13.54116*T + .6988*T2 - .01174*T3
      MT15 = 1828.604 - 207.663*T + 12.2996*T2 - .215228T3
      TPI5 = 36.524 - 1.4008*T + .1028*T2 - .00183*T3
      IF (TRIM1 - 5.0) 165,163,170
163   SHYST(HTMN) = T5
      SHYST(HLCB) = LCB5
      SHYST(HLCF) = LCF5
      KM = KM5
      SHYST(MTI) = MT15
      SHYST(HTPI) = TPI5
      GO TO 190
165   SHYST(HTMN) = ((T5-T0)*(TRIM1+0.0)/5.0) + T0
      SHYST(HLCB) = ((LCB5-LCB0)*(TRIM1+0.0)/5.0) + LCB0
      SHYST(HLCF) = ((LCF5-LCF0)*(TRIM1+0.0)/5.0) + LCF0
      KM = ((KM5-KM0)*(TRIM1+0.0)/5.0) + KM0
      SHYST(MTI) = ((MT15-MT10)*(TRIM1+0.0)/5.0) + MT10
      SHYST(TPI) = ((TPI5-TPI0)*(TRIM1+0.0)/5.0) + TPI0
      GO TO 190
C
170   T10 = 4.309 + 2.9424E-03*DISP - 4.809E-08*DISP2
            T = T10
            T2 = T10*T10
            T3 = T10*T10*T10
      LCB10 = .028397*T2 - 18.2766 - 1.0887*T
      LCF10 = .08204*T2 - 24.27 - 1.28722*T - .0014123*T3
      KM10 = 27.36 + .4337*T - 9.27E-02*T2 + 2.9915E-03*T3
      MT110 = 466.9196 + 11.9731*T + .8994*T2 - .0263*T3
      TPI10 = 24.3736 + .3121*T + 3.07E-02*T2 - 1.0013E-03*T3
      IF (TRIM1 - 10.0) 175,173,180
173   SHYST(HTMN) = T10
      SHYST(HLCB) = LCB10
      SHYST(HLCF) = LCF10
      KM = KM10
      SHYST(MTI) = MT110
      SHYST(HTPI) = TPI10
      GO TO 190
175   SHYST(HTMN) = ((T10-T5)*(TRIM1-5.0)/5.0) + T5
      SHYST(HLCB) = ((LCB10-LCB5)*(TRIM1-5.0)/5.0) + LCB5
      SHYST(HLCF) = ((LCF10-LCF5)*(TRIM1-5.0)/5.0) + LCF5
      KM = ((KM10-KM5)*(TRIM1-5.0)/5.0) + KM5
      SHYST(MTI) = ((MT110-MT15)*(TRIM1-5.0)/5.0) + MT15
      SHYST(TPI) = ((TPI10-TPI5)*(TRIM1-5.0)/5.0) + TPI5
      GO TO 190
C
180   T15 = 3.922 + .002934*DISP - 4.61E-08*DISP2
            T = T15
            T2 = T15*T15
            T3 = T15*T15*T15
      LCB15 = 1.81125*T - 58.245 - .037689*T2
      LCF15 = .509554*T - 39.03 - .008567*T2 + .0001659*T3
      KM15 = 47.204 - 3.41579*T + .15515*T2 - .002215*T3
      MT115 = 535.148 + 3.24361*T + 1.22144*T2 - .030187*T3
      TPI15 = 18.203 + 1.6673*T - .0623975*T2 + .001039*T3
      IF (TRIM1 - 15.0) 185,183,183
```

```
183   SHYST(HTMN) = T15
      SHYST(HLCB) = LCB15
      SHYST(HLCF) = LCF15
      KM = KM15
      SHYST(MTI) = MT115
      SHYST(HTPI) = TPI15
      GO TO 190
185   SHYST(HTMN) = ((T15-T10)*(TRIM1-10.0)/5.0) + T10
      SHYST(HLCB) = ((LCB15-LCB10)*(TRIM1-10.0)/5.0) + LCB10
      SHYST(HLCF) = ((LCF15-LCF10)*(TRIM1-10.0)/5.0) + LCF10
      KM = ((KM15-KM10)*(TRIM1-10.0)/5.0) + KM10
      SHYST(MTI) = ((MT115-MT110)*(TRIM1-10.0)/5.0) + MT110
      SHYST(TPI) = ((TPI15-TPI10)*(TRIM1-10.0)/5.0) + TPI10
C
C     FIND FWD AND AFT DRAFTS
C
190   SHYST(TRIM) = TRIM1 * 12.0
      SHYST(TFD) = SHYST(HTMN)-SHYST(TRIM)*
     1             ((LBP/2.)-SHYST(HLCF))/(LBP/12.)
      SHYST(TAFT) = SHYST(TFD) + SHYST(TRIM)/12.0
C
C     COMPUTE GM
      KGRISE = SUM(SFS)/SUM(SWT)
      SHYST(HGM) = KM-(SUM(SVCG)+KGRISE)
C
      SHYST(HWT) = SUM(SWT)
      SHYST(HLCG) = SUM(SLCG)
      SHYST(HVCG) = SUM(SVCG)
      SHYST(HHA) = SUM(STCG)
C
      RETURN
      END
```

SUBROUTINE CSSEQN

```
C     MODULE NAME: CSSEQN FORTRAN
C     A UNIT OF SHIP STABILITY DAMAGE CONTROL SIMULATION
C     BY J. R. SANDER LT USN
C     MIT OCEAN ENGINEER THESIS 1983
C     REVISED BY C. A. BUSH LT USN
C   . MIT OCEAN ENGINEER THESIS, SPRING 1984
C     DATE: 12 FEBRUARY 1984
C     ----------------------------------------------------------------
C     PART OF SUBGROUP: SAFETY
C     CALLING MODULES:  SUBROUTINE SSEVAL
C     CALLING ARGUMENTS: SHYST(),WHEN
C     RETURN ARGUMENTS: CSCOEF()
C     CALLED MODULES: CCEQN
C     DATA FILES OPENED: NONE
C     DATA FILES CLOSED: NONE
C     DATA FILES USED: NONE
C     PURPOSE OF MODULE: DETERMINE COEFFICIENTS FOR CURVE OF
C            STATICAL STABILITY
C            CURVE OF STATIC STABILITY IS MODELLED USING METHOD
C            OF HARMONICS AS PUBLISHED IN MIT SM IN NA+ME THESIS
C            BY BARNHART AND THEWLIS, 1948.
C            USING 8 FOURIER TERMS.
C     ----------------------------------------------------------------
      SUBROUTINE CSSEQN(WHEN,SHYST,CSCOEF)
C
      INTEGER WHEN
      REAL SHYST(13)
      REAL CSCOEF(0:8),CCGZ(0:9)
      REAL S(4),D(4)
      INTEGER A
C
      INTEGER NOW,FIN
      INTEGER HWT,HTMN,HTPI,HLCG,HVCG,HLCF,HLCB,HHA,HGM,
     1 MTI,TRIM,TFD,TAFT
      REAL LBP,PI,KGO
C
      COMMON/TIMING/ NOW,FIN
      COMMON/HSTATC/HWT,HTMN,HTPI,HLCG,HVCG,HLCF,HLCB,HHA,HGM,
     1 MTI,TRIM,TFD,TAFT
      COMMON/CONST/LBP,PI,KGO
C
      CALL CCEQN(WHEN,(SHYST(HWT)),(SHYST(TRIM)),CCGZ)
C
C     COMPUTE COEFFICIENT FOR CSS USING METHOD OF FOURIER
C     HARMONICS
      GGPRI = CCGZ(9)
C     SUBTRACT GGPRIME * SIN THETA FROM EACH TERM
      DO 105 A+1,9
         CCGZ(A)=CCGZ(A) - GGPRI*SIN(10.*REAL(A)*PI/180.)
105   CONTINUE
C
C     CALCULATE SUMS AND DIFFERENCES
```

```
      DO 115 I = 1,4
         S(I) = CCGZ(I) + CCGZ(9-I)
         D(I) = CCGZ(I) - CCGZ(9-I)
115   CONTINUE
C
C     PRECALC SIN'S
      S20 = SIN(20.*PI/180.)
      S40 = SIN(40.*PI/180.)
      S60 = SIN(60.*PI/180.)
      S80 = SIN(80.*PI/180.)
C
C     CALCULATE COEFFICIENTS
      B=2./9.
      CSCOEF(0)=GGPRI
      CSCOEF(1)=B*(S(1)*S20 +S(2)*S40 +S(3)*S60 +S(4)*S80)
      CSCOEF(2)=B*(D(1)*S40 +D(2)*S80 +D(3)*S60 +D(4)*S20)
      CSCOEF(3)=B*(S(1) + S(2) - S(4))*S60
      CSCOEF(4)=B*(D(1)*S80 +D(2)*S20 -D(3)*S60 -D(4)*S40)
      CSCOEF(5)=B*(S(1)*S80 -S(2)*S20 -S(3)*S60 +S(4)*S40)
      CSCOEF(6)=B*(D(1) - D(2) + D(4))*S60
      CSCOEF(7)=B*(S(1)*S40 -S(2)*S80 +S(3)*S60 -S(4)*S20)
      CSCOEF(8)=B*(D(1)*S20 -D(2)*S40 +D(3)*S60 -D(4)*S80)
C
C     NOTE:  GZ = GGPRIME+SUM(CSCOAF(I)*SIN(THETA*2*I))
      RETURN
      END
```

APPENDIX F COMPARISON OF IDENTICAL RUNS BETWEEN CONVENTIONAL CALCULATIONS AND TRIM EFFECTS CALCULATIONS VERSIONS OF THE STABILITY MODULE

Conventional Approach (LT Sander's Version):

WEIGHT SUMMARY
(ACTUAL)

CATEGORY	GALLONS	TONS	VCG	LCG (- AFT)	TCG (- PORT)	FRSURF
FRESH WATER	7440.	27.6	8.177	-107.13	0.000	8.4
LUBE OIL	4145.	14.3	13.684	-66.94	-15.685	4.4
FUEL OIL	69495.	217.2	7.004	20.96	0.003	576.4
JP-5	21054.	63.8	10.365	-139.00	1.983	199.4
MISC TANKS	1651.	5.4	0.892	43.12	-0.095	53.9
BALLAST	33791.	129.1	7.954	33.49	0.000	0.0
FLOODING	27325.	104.4	14.439	104.21	0.588	4336.2
AMMUNITION	0.	50.0	32.870	37.91	0.000	0.0
AIRCRAFT	1.	18.0	33.620	-102.70	0.000	0.0
PROVISIONS	0.	22.0	16.910	14.50	0.000	0.0
GEN STORES	0.	18.0	24.170	31.70	0.000	0.0
OTHR WEIGHTS	0.	0.0	0.000	0.00	0.000	0.0
CREW	0.	21.0	22.330	50.30	0.000	0.0
LIGHT SHIP	0.	2756.0	20.890	-13.79	0.000	0.0
TOTAL	0.	3446.8	19.217	-8.36	-0.011	5178.7

```
DO YOU WANT A HARD COPY? (Y/N)?  NO


         SELECT CATAGORY OF LOAD SUMMARY DISPLAY/PRINT OUTPUT

A   ACTUAL LOAD SUMMARY
F   FINAL FLOODED LOAD SUMMARY
W   WHAT IF? (DRILL) MODE SUMMARY
R   RETURN TO MAIN MENU
?R

                    CHOOSE FROM THE FOLLOWING:
L   LOADS - UPDATE AND*OR REVIEW... TANKS AND FLOODING
W   WHAT IF? - ENTER OR EXIT WHAT IF/DRILL MODE
S   STABILITY AND SAFETY EVALUATION
D   DAMAGE CONTROL EVALUATION AND RECOMMENDATIONS
    (CALLS LOADSUM AND SAFETY)
F   FAST DAMAGE CONTROL
    (SKIPS OTHER STEPS - GOES DIRECTLY TO DC)
Q   QUIT
?S

                   LOADS ARE NOW BEING SUMMED.....
```

```
            SELECT DESIRED METHOD FOR DISPLAY OF HYDROSTATICS:
H   HARD COPY ONLY
    -THE FOLLOWING CHOICES WILL RESULT IN HARD COPY PLUS:
D   DRAFT AND DISPLACEMENT ONLY
C   COMPLETE DISPLAY OF ALL FUNCTIONS
CHOICE:
?C

                    CURRENT STATUS OF SHIP AS FOLLOWS:

DRAFT:          MEAN                  AFT                     FORWARD
          14 FT  5.1 IN       15 FT  7.6 IN          12 FT 10.9 IN

DISPLACEMENT:    3446.8 TONS

TRIM:    +2 FT  8.7 IN (Note: In initial version trim was in the
                        opposite sense)
MOMENT TO TRIM ONE INCH (MTI):   751 FT*TONS/IN
TONS PER INCH IMMERSION (TPI):    31 TONS/INCH

METACENTRIC HEIGHT   (GM):                +1.7 FT
VERTICAL CENTER OF GRAVITY (KG):           19.2 FT
LONGITUDINAL CENTER OF GRAVITY (LCG):     212.4 FT FROM FRAME 0
COMPUTE TRIM MOMENTS FROM (LCB):          205.2 FT FROM FRAME 0
MEAN DRAFT OCCURS AT (LCF):               227.0 FT FROM FRAME 0
(LENGTH OF SHIP FOR TRIM CALCULATIONS:  408.0 FT)


            ENTER ACTUAL OR EXPECTED WIND VELOCITY IN KNOTS:
?100

        STATIC STABILITY IS NOW BEING EVALUATED (CURRENT STATE)


                    ** RESULTS OF STABILITY ANALYSIS **

THE FOLLOWING OBSERVATIONS AND RECOMMENDATIONS ARE BASED ON
ANALYSIS OF THE CURVE OF STATIC STABILITY:

                    (RESULTS ARE FOR CURRENT CONDITION)

             1 DEGREES OF HEEL ARE DUE TO OFF-CENTER WEIGHT
              THE RIGHTING ARM CURVE VANISHES AT 76 DEGREES
           DEEP ROLLING BEYOND 50 DEGREES COULD BE DANGEROUS.

THE SHIP MEETS THE STABILITY CRITERIA FOR OFF-CENTER WEIGHT,
BUT DOES NOT MEET THE BEAM WIND CRITERIA.

COURSES WHICH RESULT IN WIND FROM BROAD ON EITHER BEAM
(PARTICULARLY THE STARBOARD BEAM) SHOULD BE AVOIDED.

IN ADDITION, FOLLOWING AND QUARTERING SEAS SHOULD BE AVOIDED.
```

```
                    (RESULTS ARE FOR THE CURRENT CONDITION)


DO YOU WANT HARD COPY OF THESE RECOMMENDATIONS?  (Y/N)
?N


                          CHOOSE FROM THE FOLLOWING:
L   LOADS - UPDATE AND*OR REVIEW... TANKS AND FLOODING
W   WHAT IF? - ENTER OR EXIT WHAT IF/DRILL MODE
S   STABILITY AND SAFETY EVALUATION
D   DAMAGE CONTROL EVALUATION AND RECOMMENDATIONS
    (CALLS LOADSUM AND SAFETY)
F   FAST DAMAGE CONTROL
    (SKIPS OTHER STEPS - GOES DIRECTLY TO DC)
Q   QUIT
?F


                    - DAMAGE AND FLOODING IDENTIFICATION -

ALL TANKS AND COMPARTMENTS ARE NOW BEING CHECKED FOR SYMPTOMS OF
FLOODING. SUSPECT SPACES WILL BE DISPLAYED AND YOU WILL BE ASKED
TO CONFIRM WHETHER OR NOT FLOODING ACTUALLY EXISTS.

DAMAGE CONTROL IDENT:35       REP LKR OR SPACE RESPONSIBLE: REPAIR ONE
3-100-0-L DRESSING SPACE                            3-100-1-L LOUNGE
3-113-0-L CREWS HEAD                              3-124-0-L BERTHING

CURRENT STATUS:  19683. GALS  (=  75.18 TONS OR 22.2 PCT)
         +250. GAL/MIN (+=IN -=OUT).. EST FILL TIME:  ********* MIN

IS THIS FLOODING? Y-YES  N-NO D-DON'T KNOW
(DON'T KNOW ASSUMES YES)
Y
                        WHAT IS THE SOURCE OF FLOODING?
S   SHELL OPENING TO THE SEA
I   INTERNAL SOURCE - RUPTURED PIPE, FIREFIGHTING, ETC.
?I

    ENTER TIME (ELAPSED MINUTES FROM NOW)
    FOR COMPUTATION OF FINAL STATE
?60

DAMAGE CONROL IDENT:43        REP LKR OR SPACE RESPONSIBLE: REPAIR ONE
4-32-0-Q  SONAR EQUIP ROOM                     4-48-1-Q SR COOLING EQIP

CURRENT STATUS:       6484. GALS  (=  24.77 TONS OR 44.5 PCT)
        +383. GAL/MIN (+=IN -=OUT).. EST FILL TIME:  +21.158 MIN

IS THIS FLOODING? Y-YES  N-NO D-DON'T KNOW
(DON'T KNOW ASSUMES YES)
?D
```

```
DAMAGE CONROL IDENT:45         REP LKR OR SPACE RESPONSIBLE: REPAIR ONE
4-56-1-M SM ARMS MAG

CURRENT STATUS:       1158. GALS  (=  4.42 TONS OR 43.7 PCT)
        +30. GAL/MIN (+=IN -=OUT).. EST FILL TIME:  +49.767 MIN

IS THIS FLOODING? Y-YES  N-NO D-DON'T KNOW
(DON'T KNOW ASSUMES YES)
?D

WARNING:
IF ANY KNOWN FLOODING OR OTHER UNUSUAL LOAD HAS NOT BEEN DISPLAYED,
YOU SHOULD RETURN TO THE LOADS SECTION OF THE PROGRAM AND MAKE THE
APPROPRIATE INPUT.

DO YOU WANT TO :
        C   CONTINUE WITH DAMAGE CONTROL RECOMMENDATIONS
        R   RETURN TO THE MAIN MENU
?C

          FINAL STATE OF FLOODING IS NOW BEING ESTIMATED....

                     CHOOSE FROM THE FOLLOWING:
L   LOADS - UPDATE AND*OR REVIEW... TANKS AND FLOODING
W   WHAT IF? - ENTER OR EXIT WHAT IF/DRILL MODE
S   STABILITY AND SAFETY EVALUATION
D   DAMAGE CONTROL EVALUATION AND RECOMMENDATIONS
    (CALLS LOADSUM AND SAFETY)
F   FAST DAMAGE CONTROL
    (SKIPS OTHER STEPS - GOES DIRECTLY TO DC)
Q   QUIT
?F

                           WEIGHT SUMMARY
                           (FINAL FLOODED)
```

CATEGORY	GALLONS	TONS	VCG	LCG (- AFT)	TCG (- PORT)	FRSURF
FRESH WATER	7440.	27.6	8.177	-107.13	0.000	8.4
LUBE OIL	4145.	14.3	13.684	-66.94	-15.685	4.4
FUEL OIL	69495.	217.2	7.004	20.96	0.003	576.4
JP-5	21054.	63.8	10.365	-139.00	1.983	199.4
MISC TANKS	1651.	5.4	0.892	43.12	-0.095	53.9
BALLAST	33791.	129.1	7.954	33.49	0.000	0.0
FLOODING	45358.	173.3	15.433	100.86	0.526	4611.1
AMMUNITION	0.	50.0	32.870	37.91	0.000	0.0
AIRCRAFT	1.	18.0	33.620	-102.70	0.000	0.0
PROVISIONS	0.	22.0	16.910	14.50	0.000	0.0
GEN STORES	0.	18.0	24.170	31.70	0.000	0.0
OTHR WEIGHTS	0.	0.0	0.000	0.00	0.000	0.0
CREW	0.	21.0	22.330	50.30	0.000	0.0
LIGHT SHIP	0.	2756.0	20.890	-13.79	0.000	0.0
TOTAL	0.	3515.7	19.173	-6.32	-0.002	5453.6

```
DO YOU WANT A HARD COPY? (Y/N)?  NO

          SELECT CATAGORY OF LOAD SUMMARY DISPLAY/PRINT OUTPUT

A   ACTUAL LOAD SUMMARY
F   FINAL FLOODED LOAD SUMMARY
W   WHAT IF? (DRILL) MODE SUMMARY
R   RETURN TO MAIN MENU
?C

           SELECT DESIRED METHOD FOR DISPLAY OF HYDROSTATICS:
H   HARD COPY ONLY
    -THE FOLLOWING CHOICES WILL RESULT IN HARD COPY PLUS:
D   DRAFT AND DISPLACEMENT ONLY
C   COMPLETE DISPLAY OF ALL FUNCTIONS
CHOICE:
?C

                    CURRENT STATUS OF SHIP AS FOLLOWS:

DRAFT:          MEAN                AFT                   FORWARD
            14 FT  7.3 IN      15 FT  4.9 IN         13 FT  7.2 IN

DISPLACEMENT:   3515.7 TONS

TRIM:    +1 FT  9.7 IN
MOMENT TO TRIM ONE INCH (MTI):   758 FT*TONS/IN
TONS PER INCH IMMERSION (TPI):    32 TONS/INCH

METACENTRIC HEIGHT  (GM):              +1.7 FT
VERTICAL CENTER OF GRAVITY (KG):       19.2 FT
LONGITUDINAL CENTER OF GRAVITY (LCG): 210.4 FT FROM FRAME 0
COMPUTE TRIM MOMENTS FROM (LCB):      205.6 FT FROM FRAME 0
MEAN DRAFT OCCURS AT (LCF):           227.3 FT FROM FRAME 0
(LENGTH OF SHIP FOR TRIM CALCULATIONS: 408.0 FT)


            ENTER ACTUAL OR EXPECTED WIND VELOCITY IN KNOTS:
?75

         STATIC STABILITY IS NOW BEING EVALUATED (FINAL FLOODED)

                  ** RESULTS OF STABILITY ANALYSIS **

THE FOLLOWING OBSERVATIONS AND RECOMMENDATIONS ARE BASED ON
ANALYSIS OF THE CURVE OF STATIC STABILITY:

                  (RESULTS ARE FOR FINAL FLOODED STATE)

              1 DEGREES OF HEEL ARE DUE TO OFF-CENTER WEIGHT
               THE RIGHTING ARM CURVE VANISHES AT 76 DEGREES
           DEEP ROLLING BEYOND 48 DEGREES COULD BE DANGEROUS.
```

THE SHIP MEETS THE STABILITY CRITERIA FOR BOTH OFF-CENTER WEIGHT,
AND BEAM WINDS UP TO THE CURRENT WIND SPEED.

(RESULTS ARE FOR THE FINAL FLOODED STATE)

DO YOU WANT HARD COPY OF THESE RECOMMENDATIONS? (Y/N)
?N

** DAMAGE CONTROL SECTION II **

COMPARTMENTS PRESENTED IN THIS SECTION REPRESENT A SIGNIFICANT THREAT TO STABILITY BECAUSE OF THEIR HEIGHT ABOVE THE KEEL OR THE LARGE FREE SURFACE PRESENT WHEN THEY ARE NOT PRESSED UP TO 100% FULL.
(THEY ARE PRIMARILY THE PINK AND YELLOW COMPARTMENTS ON DC PLATE 1)

THE ORDER OF PRESENTATION IS NOT SIGNIFICANT IN THIS VERSION OF THIS SIMULATION. VIEW ALL ALTERNATIVES BEFORE DECIDING ON A COURSE OF ACTION.

```
DAMAGE CONTROL IDENT: 35                         REP LKR RESP: REPAIR ONE
3-100-0-L DRESSING SPACE                                 3-100-1-L LOUNGE
3-113-0-L CREWS HEAD                                   3-124-0-L BERTHING

ESTIMATED AREA OF SOURCE:     0.05 SQ FT
CURRENT STATUS:   19683. GALS   (=  75.18 TONS OR 22.2 PCT)
     +250. GAL/MIN (+=IN -=OUT)...EST FILL TIME 276.568 MIN
           EFFECT ON MEAN DRAFT:   +0.19 FT
           EFFECT ON TRIM:         +0.77 FT (CHG IN BOW TRIM)

FINAL STATUS:   34683. GALS   (= 132.48 TONS OR 39.0 PCT)
           EFFECT ON MEAN DRAFT:   +0.34 FT
           EFFECT ON TRIM:         +1.31 FT (CHG IN BOW TRIM)
```

THIS COMPARTMENT WOULD IMPROVE STABILITY MOST:
IF IT WERE COMPLETELY EMPTY.
(OR AT A MINIMUM, IF IT WERE HELD AT ITS PRESENT LEVEL)
ACTION PRIORITY CATEGORY = 1

Trim Effects Method (present version of the Stability Module):

WEIGHT SUMMARY
(ACTUAL)

CATEGORY	GALLONS	TONS	VCG	LCG (- AFT)	TCG (- PORT)	FRSURF
FRESH WATER	7440.	27.6	8.177	-107.13	0.000	8.4
LUBE OIL	4145.	14.3	13.684	-66.94	-15.685	4.4
FUEL OIL	69495.	217.2	7.004	20.96	0.003	576.4
JP-5	21054.	63.8	10.365	-139.00	1.983	199.4
MISC TANKS	1651.	5.4	0.892	43.12	-0.095	53.9
BALLAST	33791.	129.1	7.954	33.49	0.000	0.0
FLOODING	27325.	104.4	14.439	104.21	0.588	4336.2
AMMUNITION	0.	50.0	32.870	37.91	0.000	0.0
AIRCRAFT	1.	18.0	33.620	-102.70	0.000	0.0
PROVISIONS	0.	22.0	16.910	14.50	0.000	0.0
GEN STORES	0.	18.0	24.170	31.70	0.000	0.0
OTHR WEIGHTS	0.	0.0	0.000	0.00	0.000	0.0
CREW	0.	21.0	22.330	50.30	0.000	0.0
LIGHT SHIP	0.	2756.0	20.890	-13.79	0.000	0.0
TOTAL	0.	3446.8	19.217	-8.36	-0.011	5178.7

DO YOU WANT A HARD COPY? (Y/N)? NO

SELECT CATAGORY OF LOAD SUMMARY DISPLAY/PRINT OUTPUT

A ACTUAL LOAD SUMMARY
F FINAL FLOODED LOAD SUMMARY
W WHAT IF? (DRILL) MODE SUMMARY
R RETURN TO MAIN MENU
?R

CHOOSE FROM THE FOLLOWING:
L LOADS - UPDATE AND*OR REVIEW... TANKS AND FLOODING
W WHAT IF? - ENTER OR EXIT WHAT IF/DRILL MODE
S STABILITY AND SAFETY EVALUATION
D DAMAGE CONTROL EVALUATION AND RECOMMENDATIONS
(CALLS LOADSUM AND SAFETY)
F FAST DAMAGE CONTROL
(SKIPS OTHER STEPS - GOES DIRECTLY TO DC)
Q QUIT
?S

LOADS ARE NOW BEING SUMMED.....

```
           SELECT DESIRED METHOD FOR DISPLAY OF HYDROSTATICS:
H   HARD COPY ONLY
    -THE FOLLOWING CHOICES WILL RESULT IN HARD COPY PLUS:
D   DRAFT AND DISPLACEMENT ONLY
C   COMPLETE DISPLAY OF ALL FUNCTIONS
CHOICE:
?C

                CURRENT STATUS OF SHIP AS FOLLOWS:

DRAFT:           MEAN                 AFT                   FORWARD
           14 FT  4.6 IN       15 FT  6.2 IN         12 FT 11.0 IN

DISPLACEMENT:   3446.8 TONS

TRIM:    +2 FT   7.2 IN
MOMENT TO TRIM ONE INCH (MTI):   746 FT*TONS/IN
TONS PER INCH IMMERSION (TPI):    32 TONS/INCH

METACENTRIC HEIGHT   (GM):             +2.5 FT
VERTICAL CENTER OF GRAVITY (KG):        19.2 FT
LONGITUDINAL CENTER OF GRAVITY (LCG):  212.4 FT FROM FRAME 0
COMPUTE TRIM MOMENTS FROM (LCB):       212.4 FT FROM FRAME 0
MEAN DRAFT OCCURS AT (LCF):            229.0 FT FROM FRAME 0
(LENGTH OF SHIP FOR TRIM CALCULATIONS: 408.0 FT)


            ENTER ACTUAL OR EXPECTED WIND VELOCITY IN KNOTS:
?100

         STATIC STABILITY IS NOW BEING EVALUATED (CURRENT STATE)


                ** RESULTS OF STABILITY ANALYSIS **

THE FOLLOWING OBSERVATIONS AND RECOMMENDATIONS ARE BASED ON
ANALYSIS OF THE CURVE OF STATIC STABILITY:

                (RESULTS ARE FOR CURRENT CONDITION)

             1 DEGREES OF HEEL ARE DUE TO OFF-CENTER WEIGHT
              THE RIGHTING ARM CURVE VANISHES AT 77 DEGREES
           DEEP ROLLING BEYOND 45 DEGREES COULD BE DANGEROUS.

THE SHIP MEETS THE STABILITY CRITERIA FOR OFF-CENTER WEIGHT,
BUT DOES NOT MEET THE BEAM WIND CRITERIA.

COURSES WHICH RESULT IN WIND FROM BROAD ON EITHER BEAM
(PARTICULARLY THE STARBOARD BEAM) SHOULD BE AVOIDED.

IN ADDITION, FOLLOWING AND QUARTERING SEAS SHOULD BE AVOIDED.

              (RESULTS ARE FOR THE CURRENT CONDITION)
```

```
DO YOU WANT HARD COPY OF THESE RECOMMENDATIONS?  (Y/N)
?N


                       CHOOSE FROM THE FOLLOWING:
L   LOADS - UPDATE AND*OR REVIEW... TANKS AND FLOODING
W   WHAT IF? - ENTER OR EXIT WHAT IF/DRILL MODE
S   STABILITY AND SAFETY EVALUATION
D   DAMAGE CONTROL EVALUATION AND RECOMMENDATIONS
    (CALLS LOADSUM AND SAFETY)
F   FAST DAMAGE CONTROL
    (SKIPS OTHER STEPS - GOES DIRECTLY TO DC)
Q   QUIT
?F


                - DAMAGE AND FLOODING IDENTIFICATION -

ALL TANKS AND COMPARTMENTS ARE NOW BEING CHECKED FOR SYMPTOMS OF
FLOODING. SUSPECT SPACES WILL BE DISPLAYED AND YOU WILL BE ASKED
TO CONFIRM WHETHER OR NOT FLOODING ACTUALLY EXISTS.

DAMAGE CONTROL IDENT:35        REP LKR OR SPACE RESPONSIBLE: REPAIR ONE
3-100-0-L DRESSING SPACE                             3-100-1-L LOUNGE
3-113-0-L CREWS HEAD                                 3-124-0-L BERTHING

CURRENT STATUS:  19683. GALS  (=  75.18 TONS OR 22.2 PCT)
         +250. GAL/MIN (+=IN -=OUT).. EST FILL TIME:  ********* MIN

IS THIS FLOODING? Y-YES  N-NO D-DON'T KNOW
(DON'T KNOW ASSUMES YES)
Y
                    WHAT IS THE SOURCE OF FLOODING?
S   SHELL OPENING TO THE SEA
I   INTERNAL SOURCE - RUPTURED PIPE, FIREFIGHTING, ETC.
?I

    ENTER TIME (ELAPSED MINUTES FROM NOW)
    FOR COMPUTATION OF FINAL STATE
?60

DAMAGE CONROL IDENT:43         REP LKR OR SPACE RESPONSIBLE: REPAIR ONE
4-32-0-Q  SONAR EQUIP ROOM                       4-48-1-Q SR COOLING EQIP

CURRENT STATUS:      6484. GALS  (=  24.77 TONS OR 44.5 PCT)
        +383. GAL/MIN (+=IN -=OUT).. EST FILL TIME:  +21.158 MIN

IS THIS FLOODING? Y-YES  N-NO D-DON'T KNOW
(DON'T KNOW ASSUMES YES)
?D
```

```
DAMAGE CONROL IDENT:45          REP LKR OR SPACE RESPONSIBLE: REPAIR ONE
4-56-1-M SM ARMS MAG

CURRENT STATUS:       1158. GALS  (=  4.42 TONS OR 43.7 PCT)
         +30. GAL/MIN (+=IN -=OUT).. EST FILL TIME:  +49.767 MIN

IS THIS FLOODING? Y-YES  N-NO D-DON'T KNOW
(DON'T KNOW ASSUMES YES)
?D

WARNING:
IF ANY KNOWN FLOODING OR OTHER UNUSUAL LOAD HAS NOT BEEN DISPLAYED,
YOU SHOULD RETURN TO THE LOADS SECTION OF THE PROGRAM AND MAKE THE
APPROPRIATE INPUT.

DO YOU WANT TO :
         C   CONTINUE WITH DAMAGE CONTROL RECOMMENDATIONS
         R   RETURN TO THE MAIN MENU
?C

           FINAL STATE OF FLOODING IS NOW BEING ESTIMATED....

                       CHOOSE FROM THE FOLLOWING:
L   LOADS - UPDATE AND*OR REVIEW... TANKS AND FLOODING
W   WHAT IF? - ENTER OR EXIT WHAT IF/DRILL MODE
S   STABILITY AND SAFETY EVALUATION
D   DAMAGE CONTROL EVALUATION AND RECOMMENDATIONS
    (CALLS LOADSUM AND SAFETY)
F   FAST DAMAGE CONTROL
    (SKIPS OTHER STEPS - GOES DIRECTLY TO DC)
Q   QUIT
?F

                             WEIGHT SUMMARY
                            (FINAL FLOODED)
```

CATEGORY	GALLONS	TONS	VCG	LCG (- AFT)	TCG (- PORT)	FRSURF
FRESH WATER	7440.	27.6	8.177	-107.13	0.000	8.4
LUBE OIL	4145.	14.3	13.684	-66.94	-15.685	4.4
FUEL OIL	69495.	217.2	7.004	20.96	0.003	576.4
JP-5	21054.	63.8	10.365	-139.00	1.983	199.4
MISC TANKS	1651.	5.4	0.892	43.12	-0.095	53.9
BALLAST	33791.	129.1	7.954	33.49	0.000	0.0
FLOODING	48694.	186.0	15.383	104.86	0.663	4646.3
AMMUNITION	0.	50.0	32.870	37.91	0.000	0.0
AIRCRAFT	1.	18.0	33.620	-102.70	0.000	0.0
PROVISIONS	0.	22.0	16.910	14.50	0.000	0.0
GEN STORES	0.	18.0	24.170	31.70	0.000	0.0
OTHR WEIGHTS	0.	0.0	0.000	0.00	0.000	0.0
CREW	0.	21.0	22.330	50.30	0.000	0.0
LIGHT SHIP	0.	2756.0	20.890	-13.79	0.000	0.0
TOTAL	0.	3528.4	19.156	-5.72	-0.007	5488.8

```
DO YOU WANT A HARD COPY? (Y/N)?  NO

          SELECT CATAGORY OF LOAD SUMMARY DISPLAY/PRINT OUTPUT

A   ACTUAL LOAD SUMMARY
F   FINAL FLOODED LOAD SUMMARY
W   WHAT IF? (DRILL) MODE SUMMARY
R   RETURN TO MAIN MENU
?C

           SELECT DESIRED METHOD FOR DISPLAY OF HYDROSTATICS:
H   HARD COPY ONLY
    -THE FOLLOWING CHOICES WILL RESULT IN HARD COPY PLUS:
D   DRAFT AND DISPLACEMENT ONLY
C   COMPLETE DISPLAY OF ALL FUNCTIONS
CHOICE:
?C

                   CURRENT STATUS OF SHIP AS FOLLOWS:

DRAFT:          MEAN                AFT                   FORWARD
            14 FT  8.0 IN      15 FT  3.5 IN          13 FT 10.5 IN

DISPLACEMENT:   3528.4 TONS

TRIM:    +1 FT  5.0 IN
MOMENT TO TRIM ONE INCH (MTI):   752 FT*TONS/IN
TONS PER INCH IMMERSION (TPI):    32 TONS/INCH

METACENTRIC HEIGHT   (GM):                +2.5 FT
VERTICAL CENTER OF GRAVITY (KG):          19.2 FT
LONGITUDINAL CENTER OF GRAVITY (LCG):  209.7 FT FROM FRAME 0
COMPUTE TRIM MOMENTS FROM (LCB):       209.7 FT FROM FRAME 0
MEAN DRAFT OCCURS AT (LCF):            228.9 FT FROM FRAME 0
(LENGTH OF SHIP FOR TRIM CALCULATIONS: 408.0 FT)


           ENTER ACTUAL OR EXPECTED WIND VELOCITY IN KNOTS:
?75

         STATIC STABILITY IS NOW BEING EVALUATED (FINAL FLOODED)

                  ** RESULTS OF STABILITY ANALYSIS **

THE FOLLOWING OBSERVATIONS AND RECOMMENDATIONS ARE BASED ON
ANALYSIS OF THE CURVE OF STATIC STABILITY:

                  (RESULTS ARE FOR FINAL FLOODED STATE)

              1 DEGREES OF HEEL ARE DUE TO OFF-CENTER WEIGHT
               THE RIGHTING ARM CURVE VANISHES AT 77 DEGREES
           DEEP ROLLING BEYOND 43 DEGREES COULD BE DANGEROUS.
```

THE SHIP MEETS THE STABILITY CRITERIA FOR BOTH OFF-CENTER WEIGHT, AND BEAM WINDS UP TO THE CURRENT WIND SPEED.

(RESULTS ARE FOR THE FINAL FLOODED STATE)

DO YOU WANT HARD COPY OF THESE RECOMMENDATIONS? (Y/N)
?N

** DAMAGE CONTROL SECTION II **

COMPARTMENTS PRESENTED IN THIS SECTION REPRESENT A SIGNIFICANT THREAT TO STABILITY BECAUSE OF THEIR HEIGHT ABOVE THE KEEL OR THE LARGE FREE SURFACE PRESENT WHEN THEY ARE NOT PRESSED UP TO 100% FULL.
(THEY ARE PRIMARILY THE PINK AND YELLOW COMPARTMENTS ON DC PLATE 1)

THE ORDER OF PRESENTATION IS NOT SIGNIFICANT IN THIS VERSION OF THIS SIMULATION. VIEW ALL ALTERNATIVES BEFORE DECIDING ON A COURSE OF ACTION.

```
DAMAGE CONTROL IDENT: 35                    REP LKR RESP: REPAIR ONE
3-100-0-L DRESSING SPACE                           3-100-1-L LOUNGE
3-113-0-L CREWS HEAD                             3-124-0-L BERTHING

ESTIMATED AREA OF SOURCE:     0.05 SQ FT
CURRENT STATUS:   19683. GALS   (=  75.18 TONS OR 22.2 PCT)
     +250. GAL/MIN (+=IN -=OUT)...EST FILL TIME 276.568 MIN
           EFFECT ON MEAN DRAFT:   +0.19 FT
           EFFECT ON TRIM:         +0.77 FT (CHG IN BOW TRIM)

FINAL STATUS:   34683. GALS   (= 132.48 TONS OR 39.0 PCT)
           EFFECT ON MEAN DRAFT:   +0.34 FT
           EFFECT ON TRIM:         +1.31 FT (CHG IN BOW TRIM)
```

THIS COMPARTMENT WOULD IMPROVE STABILITY MOST:
IF IT WERE COMPLETELY EMPTY.
(OR AT A MINIMUM, IF IT WERE HELD AT ITS PRESENT LEVEL)
ACTION PRIORITY CATEGORY = 1

207057
Thesis
B9213 Bush
The continuation of a damage control stability module for the FFG-7.